THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR ANTOINE GHALI ELIA HABIB

TITLE OF THESIS GEOLOGY OF THE BEARPAW FORMATION IN SOUTH CENTRAL ALBERTA

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED SPRING, 1981

THE UNIVERSITY OF ALBERTA

GEOLOGY OF THE BEARPAW FORMATION IN SOUTH CENTRAL ALBERTA

by

© ANTOINE GHALI ELIA HABIB

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

GEOLOGY

EDMONTON, ALBERTA

SPRING, 1981

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled GEOLOGY OF THE BEARPAW FORMATION IN SOUTHCENTRAL ALBERTA submitted by ANTOINE GHALI ELIA HABIB in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in GEOLOGY.

ABSTRACT

A subsurface study of the Upper Cretaceous Bearpaw Formation using 668 borehole electric logs was carried out to map the subsurface distribution, geometry, lithologic variation and subdivisions of the formation in southcentral Alberta. Correlations between the interpreted fluctuations in water depths from lithology alone, from foraminifera and from other studies permitted interpretation of the depositional environment of the Bearpaw Formation in the study area.

In southcentral Alberta, six cycles of coarsening-upward deposits are recognized above the sands of the Judith River Formation. The Bearpaw Formation consists of the lower five of these cycles and the fine fraction of the uppermost sixth cycle. The coarse fraction of the sixth cycle forms the basal beds of the overlying Horseshoe Canyon Formation. The cycles are informally designated in ascending order as cycle A, B, C, D, E and F. Each cycle consists of a lower shale or silty shale unit which is overlain by a sandstone or sandy siltstone unit and the top of a cycle is often marked by the presence of a bentonitic clay which is overlain by a coal seam. The shale units of all cycles are generally thinner in the north and west and are wedge-shaped and relatively thick in the south and east of the study area. The sandstones of the Bearpaw Formation are thick along east-west trending channel-like features and the sands

are relatively thinner and sheet-like between the channels. All the units of the cycles can be traced over large distances across the area in the subsurface with the exception of the shales of cycle E and F that are not present in the western part of the study area.

Five major episodes of increase in water depths are indicated by the deposition of shales of cycle A, cycle C, cycle D, cycle E and cycle F of the Bearpaw Formation. Two minor fluctuations are suggested by the deposition of shales of cycle B and the shales at the base of the lower part of cycle D. The major fluctuations in water depth that occurred during the deposition of the Bearpaw Formation in southcentral Alberta are correlative with the five fluctuations that were recognized by Given (1969) and by Given and Wall (1971) from the profusion of calcareous foraminifera in these parts of the formation in the R.C.A. Castor Well.

Deposition of the Bearpaw Formation in southcentral Alberta took place in a relatively shallow marine deltaic environment which was associated with the movement of a shoreline westward and eastward across the area. The different deltaic subenvironments are represented by prodelta shales that grade into silts and sands of the delta front and distributary mouth bar facies and finally into coals of the swamp environment.

ACKNOWLEDGEMENTS

The study of the subsurface geology of the Bearpaw Formation in southcentral Alberta was sponsored by the department of geology of the University of Alberta through Dr. G.D. Williams, and the author is indebted to both the department and Dr. Williams for their support.

The author wishes to thank Dr. Williams for suggesting the topic, supervising the study and for editing the manuscript.

Thanks are due to Dr. C.R. Stelck and Dr. J.F. Lerbekmo for their constructive advice about the study.

The Research Council of Alberta is acknowledged for giving access to borehole log information and thanks are due to Dr. J. Kramers and Dr. R.A. Rahmani for their support.

Shell Canada Resources Limited supplied base maps for the area of study and drafted the maps and illustrations present in the thesis, and the author is thankful to Shell for their help.

Thanks are also due to my wife Georgette for her support and for typing the first draft of the manuscript.

Table of Contents

List of Tables

List of Figures

Figure		Page

I. INTRODUCTION

Epicontinental seas flooded the western interior of North America several times during Late Cretaceous time. The last of these inundations deposited the Bearpaw Formation in Alberta and neighbouring areas of the interior.

Previous studies indicate that the Bearpaw was deposited in a single transgression-regression cycle during a period of advance and gradual retreat of the Bearpaw Sea over the area.

The western margins of this great seaway often retreated from the west as great masses of sediments were periodically eroded from youthful mountains and deposited along the shoreline. Partial withdrawal of the sea gave way to the formation of swamps and shallow environments where coal and shoreline sands were deposited. As the sea struggled back and forth, the influx of sediments progressively drove the waters gradually to the east, south and possibly north until finally the sea withdrew completely from the interior towards the end of the Cretaceous time, leaving only imprints of its existence.

A. Scope of the Study

The purpose of this work was to study the subsurface geology of the Bearpaw Formation in southcentral Alberta. The objectives can be detailed in point form as follows:

1. To correlate in detail the Bearpaw Formation in the

subsurface.

2. To delineate the geometry and distribution of the formation in the area of study.
3. To subdivide the Bearpaw Formation into individually mappable units on the basis of specific electric log signatures.
4. To relate the findings of this work to studies made in the surrounding areas.
5. To suggest a depositional model for the Bearpaw sediments.
6. To indicate the relative position of the shoreline during the deposition of each unit of the Bearpaw Formation.

B. Area of Study

The area under study lies between Calgary and Red Deer in southcentral Alberta, between Township 36 in the north and Township 25 in the south. Control is limited to the east by wells that were spudded in the lower Edmonton Group, as the upper part of the Bearpaw Formation is concealed by surface casing. The western limit of the study approximately follows the eastern limit of the disturbed belt where the inferred margin of the Bearpaw sea has been placed (figure 1). The study covers approximately 200 townships or 8,748 square miles (13,542 square kilometers).

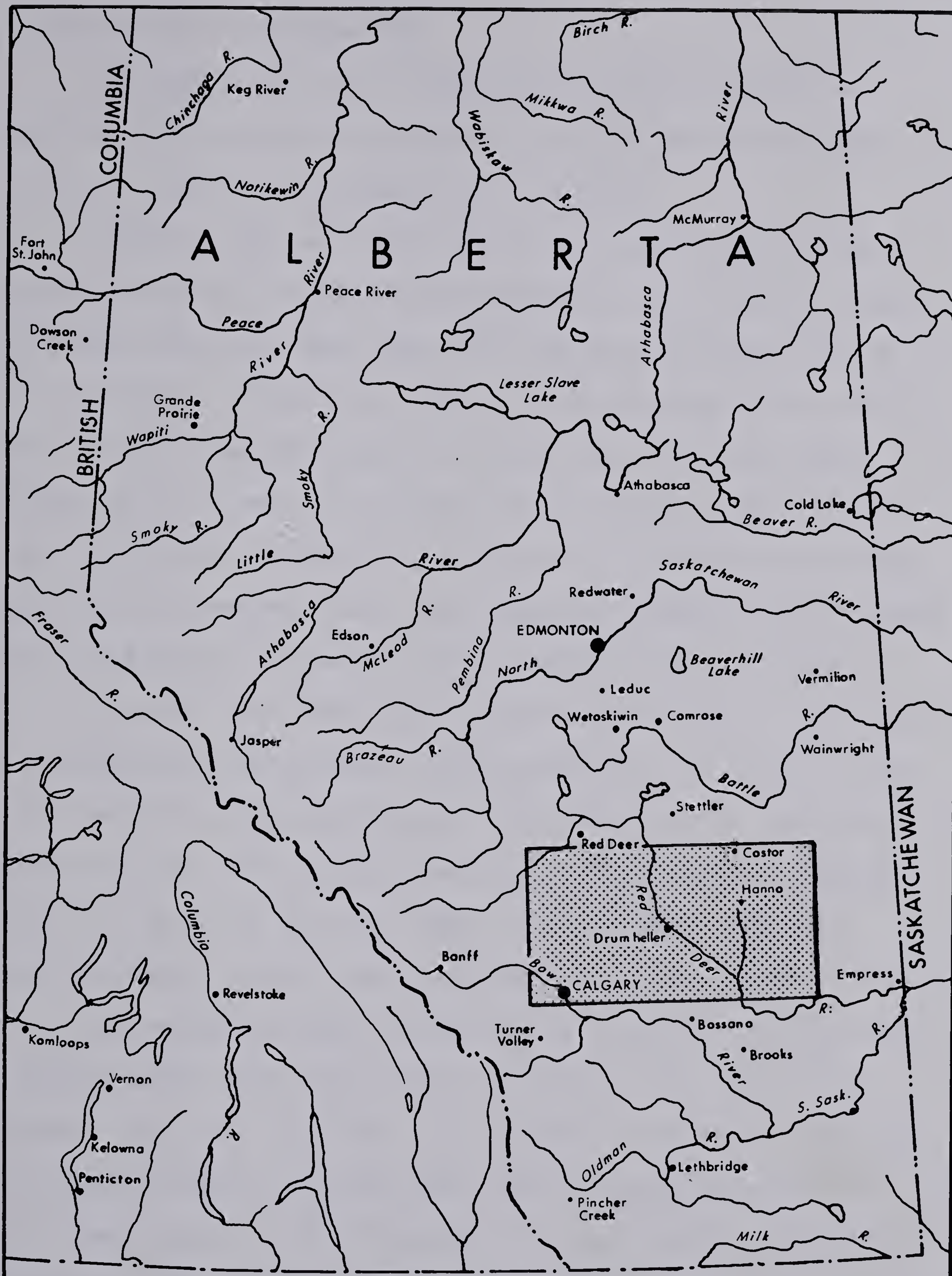


Figure 1. Location map of the area of study.

C. Method of Investigation

The major portion of information for the study was derived from geophysical borehole logs on microfilm from files of the Research Council of Alberta.

Electric logs were the major tool used in the study, supplemented by radiation and porosity logs. Electric logs from 668 boreholes were used for the detailed analysis of the formation (figure 2). Tops of the Colorado Shale, the Milk River Formation marker and the Lea Park Shale were picked for 324 wells and depths were recorded. The top of the Judith River Formation, the base of the Edmonton Group and tops of markers within the Bearpaw Formation were picked for the 668 wells studied and the depths were tabulated.

Electric logs from 324 boreholes were used to construct six detailed stratigraphic cross sections, utilizing a one to three miles spacing between individual wells along each cross section. Correlation was begun from a central point (Lsd. 5, Sec. 34, Twp. 30, Rge. 22, W. 4 Mer.) and was carried north, south, east, and west from that point.

The secondary phase commenced by using control points already established and correlating back in a loop in an attempt to close the loop. Five township (30 miles) spacing was used between cross sections running east to west that is, along Township 25, Township 30, and Township 36. North to south cross sections were constructed along Range 2 west of the Fifth Meridian, and Ranges 22 and 19 west of the Fourth Meridian.

FIGURE 2

Location Map of Wells Studied

BEARPAW FORMATION

South Central Alberta

By Antoine G.E. Nabib University of Alberta, 1981

Scale 1" = 32 000'

◇ Wells Studied

The final phase in the correlation established the link between the major cross sections. At this stage the markers established were picked in an east to west direction starting in Township 26, then carried north to Township 32 and to Township 36 east of Range 22 west of the Fourth Meridian.

II. GENERAL GEOLOGY

A. Previous Studies

The first delineation of the Bearpaw Formation was done by Hatcher and Stanton (1903) and Stanton and Hatcher (1905), in Montana. They named the formation for the Bearpaw Mountains where the shales are well exposed along the north, east and south slopes. They recognized that the formation extended into southern Alberta in the Cypress Hills where it was mapped by Canadian geologists (Dawson, 1882, 1884) as Pierre Shales (figure 3).

Dowling (1917) introduced the term, Bearpaw Shale, to Canadian literature in southern Alberta where the formation is well exposed along the banks of the Oldman River from Ryegrass flat to Piyami Coulee, and near the mouth of St. Mary River. Dowling listed the invertebrate fossils found in the formation and determined the thickness to be 622 feet (189.6 meters) in the area.

Williams and Dyer (1930) recognized the Bearpaw Shales along the creeks draining the north slopes of the Cypress Hills and along both flanks of the Sweet Grass Arch. Sands were reported within the lower part of the formation and a prominent sandstone marker was reported from the middle part of the unit to the north.

Detailed stratigraphy of the Bearpaw Formation in the Lethbridge area was presented by Link and Childerhose (1931), where the lower boundary of the shale is well marked

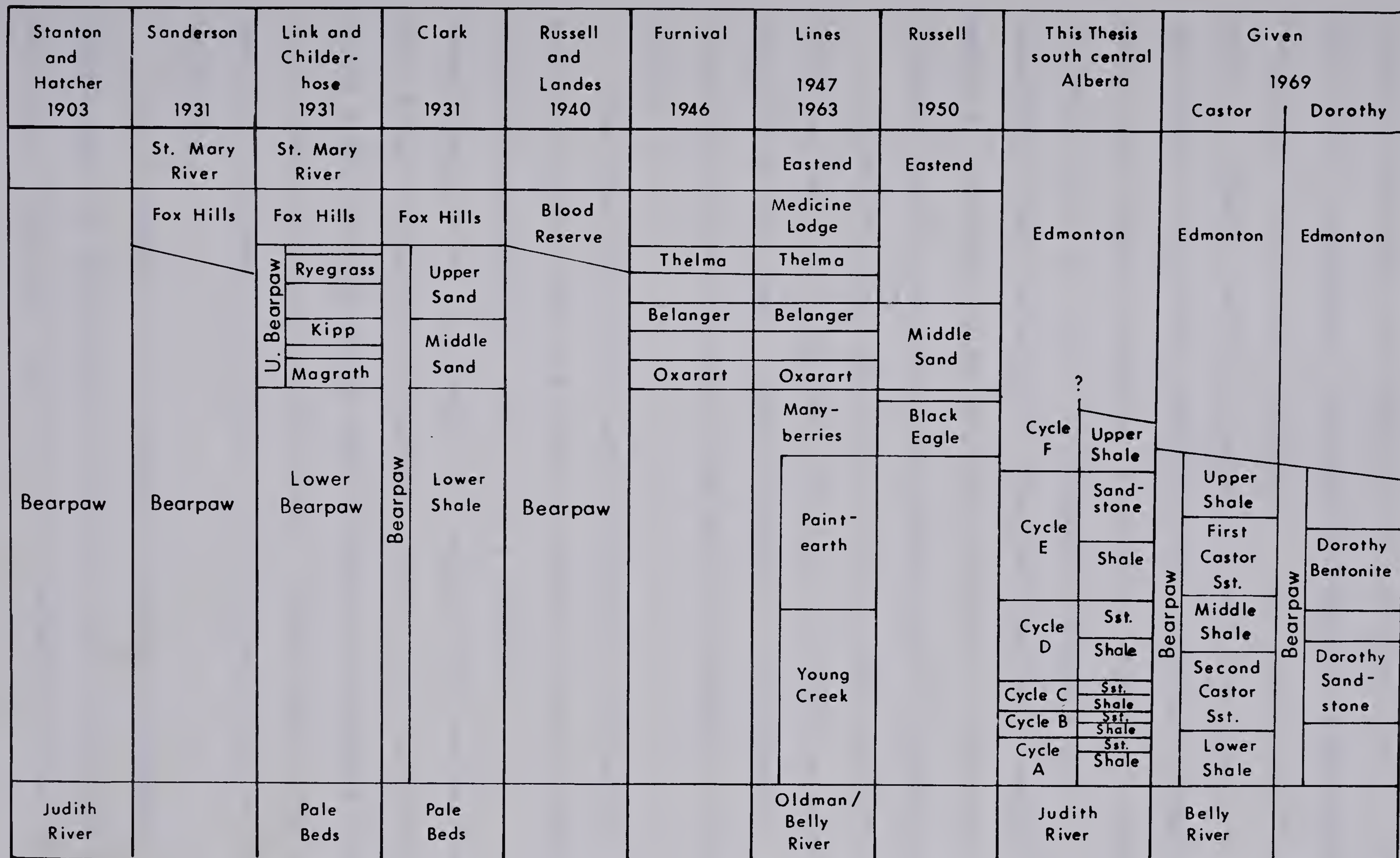


Figure 3. Local terminology for the Bearpaw Formation.

by the Lethbridge coal measures of the upper part of the Belly River succession. Link and Childerhose subdivided the Formation into two parts namely "... the lower one-third, which is almost devoid of sands ..., and the upper two-thirds, containing three distinct sandstone members or zones, and lighter bluish or steel-gray, somewhat sandy, shales" (1931, p. 1231). The sandstone members are in ascending order the Magrath, Kipp and Ryegrass Sandstone members. Bentonite seams and limy ironstone concretions with numerous fossils were also described from the Formation.

A similar study was done by Clark (1931) between Keho Lake and Bassano in southern Alberta, in which he reported a thinning of 230 feet in the thickness of the Bearpaw Formation from Keho Lake in the south to Bassano in the north.

The name "Fox Hills" was proposed for the marine sandstone above what was then considered to be the Bearpaw Formation by Sanderson (1931). This sandstone lies immediately below the basal coal seam of the non-marine St. Mary River Formation in southern Alberta, and is considered to be a well sorted beach sand ranging in thickness from 31 to 327 feet south of the Bow River, thickening to the west. North of the Bow River the Fox Hills Formation could not be identified.

The thickness of the Bearpaw Formation southwest of Lethbridge was determined by Yarwood (1931) to be 690 feet and that of the overlying Fox Hills Formation to be 135 feet

thick.

Warren (1931) illustrated the megafauna of the Bearpaw Formation and indicated their long vertical range representing most of Cretaceous Montana time. The fauna of the Fox Hills Formation contained Bearpaw marine forms as well as brackish-water forms.

Wickenden (1932) published the first microfaunal data from the Bearpaw Formation in southern Alberta, but no stratigraphic correlation was attempted.

The Bearpaw Formation of Saskatchewan was correlated with its counterpart in Alberta on the basis of its stratigraphic position and faunal content by Fraser *et al.* (1935).

Russell and Landes (1940) studied the relative changes of land and sea during Late Cretaceous time in southern Alberta. They proposed the term "Blood Reserve Formation" for the sandstone bed at the top of the Bearpaw Formation, to replace the term "Fox Hills".

Furnival (1946) revised the interpretation of the Bearpaw Formation and ascribed to it all the marine, dark grey, Pierre shales below the "Brown Sandstone Member" of the Fox Hills in eastern Montana, and above the Judith River Formation. Furnival introduced the names "Thelma", "Belanger" and "Oxarart" for the three successively older sandstone members of the Bearpaw Formation in southwest Saskatchewan. These sandstones were determined to be 30 to 50 feet thick at the Alberta-Saskatchewan boundary and to

pinch out about 40 miles east of the boundary.

This terminology was applied by Lines (1947) to outcrops along the western slopes of the Cypress Hills in Alberta, where he established two new members. The term "Manyberries" was used to differentiate the non-sandy lower portion of the Bearpaw Formation from the upper sandier portion. The term "Medicine Lodge" was applied to the dark grey shales above the Thelma Member and below the top of the formation.

On the basis of bentonite correlations between Cypress Hills and the Lethbridge area, Lines suggested that the Bearpaw Sea transgressed rapidly and that the top of the Oldman or Belly River Formation is practically isochronous. He also recognized that the Bearpaw Formation thins slightly in the Lethbridge area and suggested that the Oxarart Sandstone of the east is equivalent to the Blood Reserve Formation of the western region.

Lines (1963) stated that the formation is more arenaceous to the north where he studied a composite section from the Castor area, suggesting that the Formation passes into non-marine beds near the shoreline. He proposed a two-fold division of the Bearpaw Formation for this section, and considered the two members to be equivalent to the lower half of the Manyberries Member in the south. The two members are the Paintearth above and the Young Creek below, separated by a chert pebble bed. The chert pebble bed was suggested as the equivalent of the basal Edmonton

conglomerate of the north-central Foothills area, assuming the diachroneity of the upper boundary of the Bearpaw Formation.

Russell's (1950) correlation of the upper part of the Bearpaw Formation between Alberta and southwestern Saskatchewan differed in detail from Furnival (1946). Russell recognized three distinct sandstone members in the upper part of the Bearpaw Formation in southeastern Alberta. He found that the lower sandstone was equivalent to a sandstone which occur 40 feet below the true Oxarart of southwestern Saskatchewan and proposed the name Black Eagle for that sandstone. He correlated the middle sandstone of southeastern Alberta with the Oxarart and Belanger sandstones of southwestern Saskatchewan, and agreed with Furnival on the correlation of the Thelma member of southwestern Saskatchewan with the upper sandstone of southeastern Alberta.

The time interval represented by the Bearpaw Formation would become less and less towards the north and west as suggested by Russell (1950). However, he stated that the base of the formation seemed to be nearly the same age everywhere, thus indicating a rapid transgression and a step by step regression of the Bearpaw Sea.

Loranger and Gleddie (1953) divided the Bearpaw Formation into six zones on the basis of microfaunal content; five of these contain abundant microfauna, based on a study of foraminifera recovered from core samples in

southwestern Saskatchewan. The formation is 1030 feet (313.94 meters) thick in that area and they indicate that three of the zones are present in the Lethbridge area but in a more brackish environment. The Blood Reserve Formation was reduced to member status by these authors and they substantiated the conclusions of Russell (1950) that the top of the Bearpaw Formation is approximately 200 feet above the top of the Oxarart Sandstone and that the section above the Oxarart in the plains area is equivalent to the basal part of the St. Mary River Formation in the foothills belt area.

Williams and Burk (1964) noted variations in thickness of the Bearpaw Formation to the west and northwest of the southern plains, such that the formation is probably not present north of the Bow River in the west, and that it grades into the basal Edmonton Formation about 50 miles northwest of the city of Edmonton in Alberta.

Caldwell and North (1964) and North and Caldwell (1970, 1975) established five microfaunal zones for the Bearpaw Formation in southwestern Saskatchewan. On the basis of foraminiferal distribution, they correlated the Bearpaw in the south Saskatchewan River valley with that of the Cypress Hills and Frenchman River valley. These authors noted that the youngest fauna found in the Oxarart and Medicine Lodge Members extends only into the basal beds of the Eastend Formation, and above these beds foraminifers disappear.

> "Such a distribution supports the view, expressed by others, that the Eastend Formation records the transition from marine to non-marine conditions denoting retreat of the Bearpaw Sea from

> southwestern Saskatchewan and the establishment of the continental conditions that were to prevail until the end of Cretaceous time." (North and Caldwell, 1975, p.324).

Many authors contributed to the age determination of the Bearpaw Formation; Folinsbee *et al.*: (1960, 1961, 1965, 1970) by potassium argon methods; Jeletzky (1968) by *Baculites* zonation that was earlier introduced by Landes (1940), and adopted by Cobban and Reeside (1952) for the western interior of the United States.

Shepheard and Hills (1970) described and interpreted, from a detailed sedimentological analysis, the conditions of deposition in the transition zone between the Bearpaw and Horseshoe Canyon Formations (the Horseshoe Canyon Formation is the lower part of the Edmonton Group). Data for their study were derived from 32 stratigraphic sections described approximately ten miles southeast of Drumheller.

Mello (1969) used foraminiferal studies to infer the paleoecology of the upper part of the Pierre Shale in north central South Dakota. North and Caldwell (1970, 1975) interpreted the paleogeography from similar studies in Saskatchewan and Given (1969) and Given and Wall (1971) used foraminifers to correlate the Bearpaw Formation between areas of southeastern Alberta.

Microfaunal studies of the Bearpaw Formation are documented in several unpublished theses. Given (1969) illustrated the foraminifera of the Bearpaw Formation in central southeastern Alberta, Rosene (1972) studied the

microfauna in the Lundbreck area in southwestern Alberta, Anan-York (1969) made similar studies in the Lethbridge area, and Harland (1970) studied the dinoflagellates and acritarchs of the Bearpaw Formation in southern Alberta.

Related recent studies are to be found in Caldwell (1975) where several authors dealt with the paleogeography of the Bearpaw Formation and its depositional environment. The following contributions in Caldwell (1975) are noteworthy. Williams and Stelck (1975) illustrated the paleogeography of the Late Cretaceous seas. Reiskind (1975) interpreted the paleoecology from a study of fossiliferous concretions from the Bearpaw Formation of eastern Montana and southwestern Saskatchewan. Wall (1975) correlated the lower part of the Bearpaw Formation in southern Alberta on the basis of diatoms, confirming that the basal beds of the formation are younger in central Alberta than in the south of the province and that the contact of the Bearpaw and underlying Judith River Formation (formerly Belly River) rises diachronously to the north. This agrees with a similar conclusion (Caldwell, 1968) established by the disappearance of ammonite zones progressively westwards from the Saskatchewan River valley to the Cypress Hills.

Wall (1975) suggested from the increase in the degree of pyritization of diatoms and radiolarian tests to the west of the Cypress Hills area, that there was a shallowing of the sea to the west with the waters becoming stagnant, probably due to restricted circulation in local depressions

on the sea floor.

A study by Given and Wall (1971) in the Castor area of Alberta is of direct relation to the present work as a complete core of the Bearpaw Formation is described and related to an electric log of the borehole. The geophysical log response provided a link between this work and their findings in the Castor area which lies at the northeastern corner of the study area.

B. Description of the Bearpaw Formation

The Bearpaw Formation consists of dark clays with numerous fossiliferous calcareous concretions in its type locality on the slopes of the Bearpaw Mountains in Montana (Stanton and Hatcher, 1905). There the dark clays directly overlie non-marine deposits of the Judith River Formation and attain a thickness of several hundred feet. They are identical in their fauna and lithologic features to part of the Pierre Formation of South Dakota. In western Canada, the Bearpaw Formation ranges in age from late Campanian to early Maestrichtian time (Jeletzky, 1968), represented by most of the *Baculites compressus* Zone of Landes (Landes, 1940; Cobban and Reeside, 1952) in the Plains and Foothills regions of western North America. A potassium-argon age determination on a bentonite (Folinsbee *et al.*, 1960, 1961) 65 feet above the base of the Bearpaw Formation gave a date of 75 ± 4 million years.

The Bearpaw Sea is known to have extended as far north

as the Edmonton area (Feniak, 1944), but the northern and eastern limits of the sea in Saskatchewan and Manitoba are unknown as the present distribution of the formation is controlled by post-Bearpaw erosion. Several occurrences of supposedly Late Campanian shales in the Northwest Territories in the area between Great Bear Lake and the Richardson Mountains suggest that the Bearpaw Sea may have extended to the Arctic through northern Saskatchewan (Martin, 1961).

In Alberta, outcrops of the Bearpaw Formation may be divided into three main belts, namely the western belt, the central outcrop belt and the eastern outcrop belt (Russell, 1950), the latter of which extends into southern and southwestern Saskatchewan.

The western belt is within the Foothills of the Rocky Mountains, and being on the western limb of the Alberta syncline, the strata dip strongly eastward. In this region the formation thickness is difficult to determine due to faulting and folding. The formation is probably no longer present north of the Bow River in the west (Williams and Burk, 1964).

The central outcrop belt extends from the Foothills to the Sweetgrass Arch and from the United States border to about 50 miles northwest of Edmonton (Feniak, 1944). The Bearpaw Formation is generally absent from the structurally high Sweetgrass arch where older strata are exposed (Williams and Dyer, 1930; Russell, 1950). The thickness of

the formation is about 810 feet in the south (Lines, 1963), and gradually thins to the north and west. East of Calgary, the Bearpaw Formation is about 350 feet thick and it is 100 feet thick or less west of Edmonton (Williams and Burk, 1964).

The eastern outcrop belt of the Bearpaw Formation is in the Cypress Hills where the formation attains a thickness of about 1030 feet (Loranger and Gleddie, 1953). This outcrop belt extends into southwestern Saskatchewan where it forms the bedrock surface over the greater part of the area (Caldwell, 1968).

According to Lines (1963), the lower contact of the Bearpaw Formation with the underlying non-marine Oldman or Judith River Formation is sharp and apparently conformable, representing a rapid transgression of the sea. The contact is placed at the top of the uppermost coal-bearing and carbonaceous shale beds of the Belly River Formation (Ower, 1960).

The upper contact of the Bearpaw formation with the non-marine Edmonton, St. Mary River, or Eastend Formation is gradational and diachronous. The sandstones of these formations replace the shales of the Bearpaw vertically in the section as well as laterally to the north and west (Williams and Burk, 1964).

The Bearpaw shales are marine and generally dark grey, weathering to brownish-grey; silty shales are usually brownish-grey. Fresh shales may be blocky or laminar, and

selenite crystals and iron oxide staining are frequently present on outcrop surfaces (Given, 1969).

The sandstone beds of the Bearpaw Formation are medium to fine grained and often glauconitic. Numerous sandy lenses are present locally but are not believed to be continuous over any great distance.

Clay ironstone concretions are present within the Bearpaw Formation, are often fossiliferous and may provide local marker beds. Bentonite beds are common in the formation, ranging from a fraction of an inch thick to as much as 8 inches thick in the Lethbridge area and are also useful local markers. Coal beds ranging from one foot thick to as much as four feet thick are present especially within the sandy intervals of the Bearpaw Formation, and provide excellent local markers (Link and Childerhose, 1931).

III. STRATIGRAPHIC ANALYSIS

A. Introduction

This chapter is concerned with the subsurface distribution, geometry, and vertical and lateral variation of the Bearpaw Formation in southcentral Alberta as determined in this study. The formation is exposed along the eastern limit of the study, within the northern part of the central outcrop belt of Russell (1950).

A study of a complete core of the Bearpaw Formation at Castor and surface exposures on the Bow and Red Deer Rivers (Given, 1969; Given and Wall, 1971) provided means for relating subsurface investigations to studies made on outcrops and core descriptions.

B. Limitations

The present study was based entirely on data from electric and radiation logs from petroleum exploration boreholes. Data obtained from these logs is subject to several limitations. The shape and magnitude of deflections of the log curves are basically a record of the variation or contrast in electrical or radiation response of the strata logged. However, additional factors such as variable sizes of boreholes (caving, etc.) and different types of drilling fluids influence the response of the logging device. The resultant shape of the curve is a reflection of the lithological variation as well as the influence of these

factors from well to well, thus curves for a similar stratigraphic section may be different quantitatively but comparable qualitatively. Additional variability stems from the fact that the the logs used in this analysis were produced by various logging companies with their patent logging techniques, in some instances using different scales for recording the parameters being logged. A third limiting factor is the variably reduced response of the spontaneous potential curve in sandstones within shaly formations such as the formation under study.

In addition to these three main limitations, the subjective personal error in the process of lithological interpretation of both types of logs by a worker must be considered.

Marker horizons and contacts for the various subsurface stratigraphic units have been qualitatively determined by the curve characteristics of the logs. No attempt was made to examine the influence of various disturbing factors on the quantitative interpretation of the log curves for the purpose of this study. Sandstones and shales and their transitions are the only lithologies involved in this study; generally the sandy zones are intercalated with silty and shaly material, and thus the boundaries between the units tend to be gradational. In particular the lower boundary of the Bearpaw Formation was difficult to determine as the upper part of the Judith River Formation consists of green shales and carbonaceous shales that produce similar

responses on geophysical logs to the shales of the Bearpaw Formation.

C. Bearpaw Formation Contacts

The Bearpaw Formation is defined by Allan and Sanderson (1945) as the dark, argillaceous, marine beds which overlie the Belly River (Judith River) Formation. They believed that the lower contact is everywhere sharply defined, but that the upper contact with the Edmonton Formation is gradational and indistinct. In southern Alberta the lower contact of the Bearpaw Formation is placed at the top of the Lethbridge coaly and carbonaceous member of the Judith River Formation. The Lethbridge member is not clearly represented in the area of study and adjacent localities, and the contact was placed at the top of the uppermost sandstone of the Judith River Formation by Ower (1960), and at the top of carbonaceous beds of that formation by Given and Wall (1971). Elliot (1960) lowered the base of the Bearpaw by 200 feet from that of Ower (1960) according to petroleum borehole data on the uppermost sand in the Judith River Formation.

In east central Alberta the top of the Bearpaw Formation becomes transitional according to Shaw and Harding (1949), and progressively grades into the overlying continental beds of the Horseshoe Canyon Formation to the northwest. The Bearpaw Formation of the south Saskatchewan River valley contains sand members that are widely distributed and valuable as markers. Caldwell (1968)

demonstrated that some of the lower sands within the Bearpaw are continuous with sands of the Judith River Formation, and that a similar relationship is probably present for the upper sands of the Bearpaw Formation and their continental counterparts in the Horseshoe Canyon Formation.

In agreement with Caldwell's interpretation, the distribution and variation of units in the Bearpaw Formation in the area of study indicate that the upper and lower contacts of the formation are transitional. Sandstones are widespread and continuous, but the position of the change from brackish-fresh water sandstones to marine sandstones of the Bearpaw could not be determined as the study was limited to subsurface correlations based on geophysical logs.

The lower contact of the Bearpaw Formation is placed at the top of the uppermost fining-upward sequence of the Judith River Formation. The top of the fining-upward sequence is placed at the uppermost sandstone bed in the sequence, and the shale unit overlying the sandstone is considered the basal bed of the Bearpaw Formation.

The contact between the Bearpaw Formation and the overlying Horseshoe Canyon Formation is placed at the top of the uppermost shale unit of the Bearpaw Formation and at the base of the lowermost continental sandstone of the Horseshoe Canyon Formation.

D. Log Signature

Typically, the log signature for the top of the Judith River Formation is a gradational right deflection towards the shale line of the spontaneous potential curve, (figure 4), generally less than five millivolts, combined with a deflection to the left (a decrease) of the resistivity curve. Similar responses are noted on radiation and density logs that occasionally accompany electric logs, but to maintain consistency only electric logs are presented and tabulated in this study.

Similarly the base of the Horseshoe Canyon Formation is taken at the base of the first significant indication of consistent continuous sandstone (negative spontaneous potential, positive resistivity) above the Bearpaw Shales which are replaced by sandstones of the basal Horseshoe Canyon Formation.

E. Subsurface Correlation

Almost all the Bearpaw succession of the study area is represented in the Research Council of Alberta Castor well studied by Given and Wall (1971) (Lsd. 13, Sec. 34, Twp. 37, Rge. 13, W. 4 Mer). Their terminology (figure 5) has been used where appropriate due to the proximity of their study and the consistency of log signatures.

Six coarsening-upward cycles are recognized in the Bearpaw succession of the study area. The five lower units are named A to E, the lower part of the uppermost cycle is

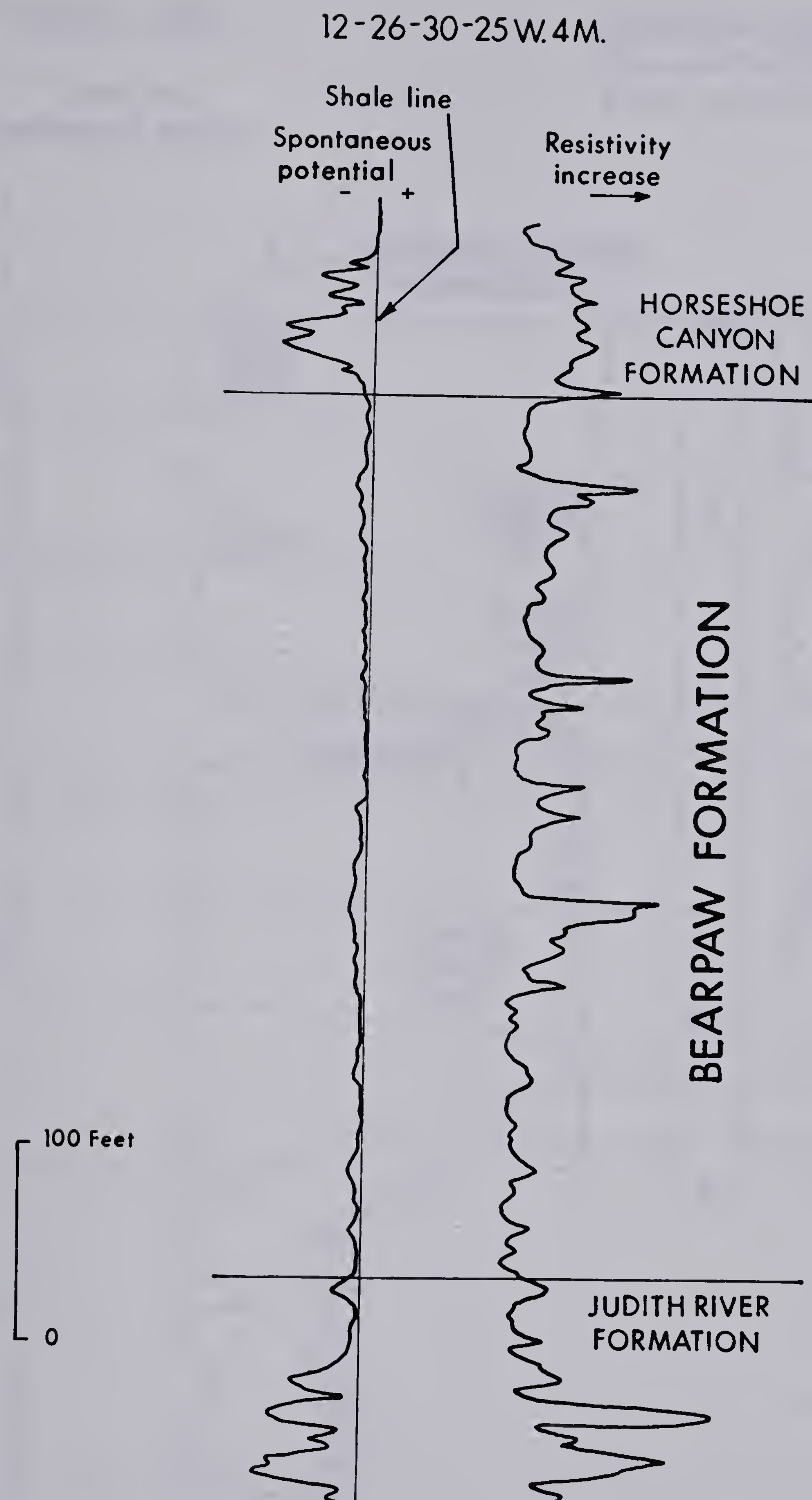


Figure 4. Electric log signature of the Bearpaw and adjacent Formations, Southcentral Alberta.

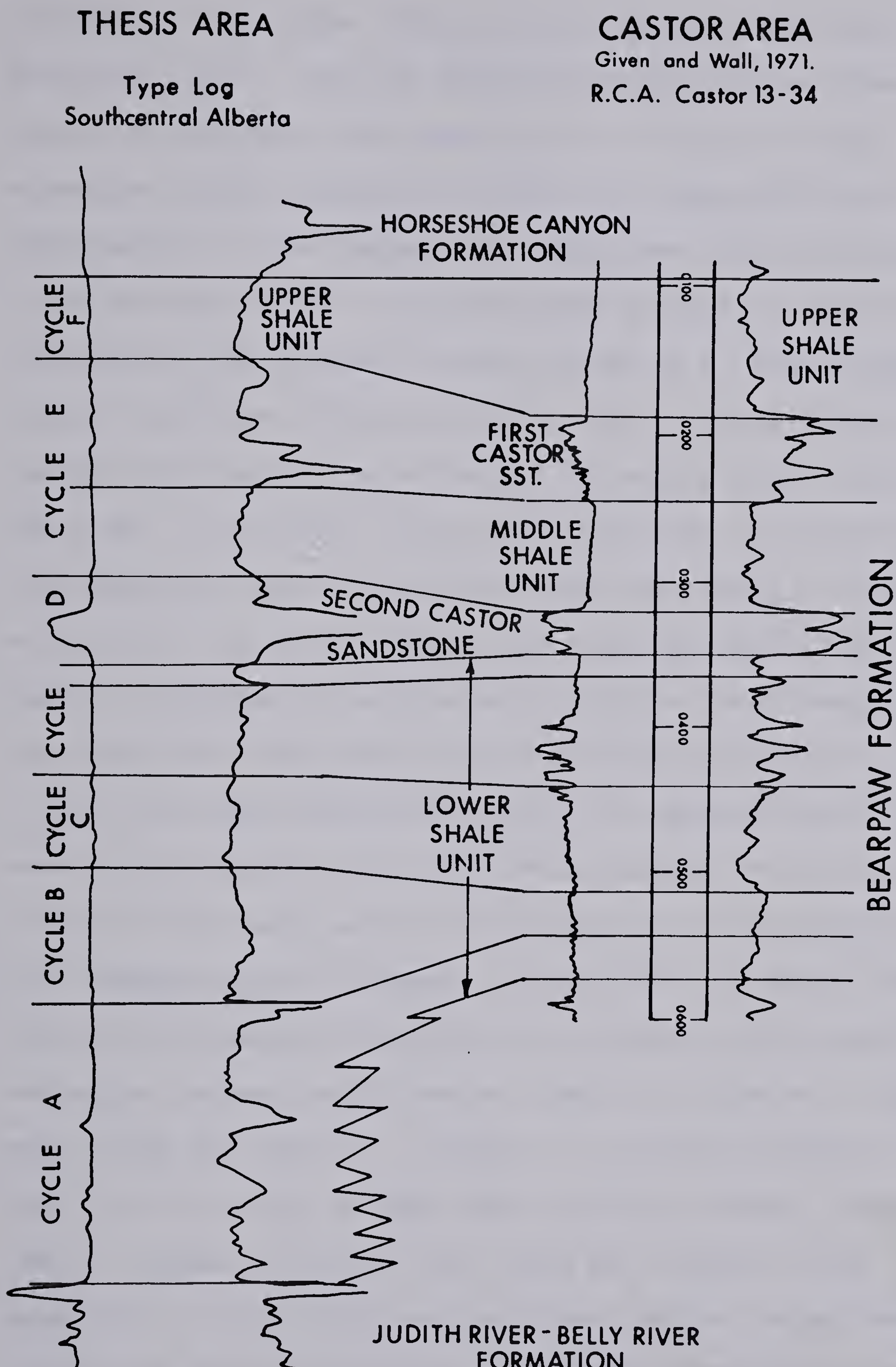


Figure 5. Correlation of the Bearpaw Formation between Castor and the area of study.

referred to the Upper Shale Unit of Given (1969) and Given and Wall (1971), and the coarse fraction of the uppermost cycle is considered the basal unit of the overlying Horseshoe Canyon Formation. Cycle A is apparently not represented in the Castor well. The Lower Shale Unit of Given and Wall (1971) is equivalent to beds in cycle B to the base of the coarse fraction of cycle D. The Second Castor Sandstone (Given and Wall, 1971) is equivalent to the coarse fraction of cycle D which is widely distributed in the area. To the west, this sand increases in thickness and replaces the clays and silts of the underlying finer portion of cycle D. The Middle Shale Unit and the overlying First Castor Sandstone are equivalent to cycle E and respectively represent the fine and coarse fractions of the cycle. Cycle E shows the same relationship that is represented by the underlying cycle D, *viz.* the sands replace the shales and silts of the lower part of the cycle until the Middle Shale Unit wedges out to the west. In addition the Upper Shale Unit of the Bearpaw Formation is replaced by the overlying Horseshoe Canyon Sands (coarse fraction of cycle F) to the west along the section, (figure 6), and most probably to the north of the study as mentioned by other workers (Russell, 1950). Tongues of sand, that could be traced in the subsurface to the north and northwest appear occasionally within the Upper Shale Unit, and these relationships merit further investigation. The lower sands of the Horseshoe Canyon Formation climb stratigraphically to the east and

southeast as demonstrated by thickening of the Upper Shale Unit in those directions which is in agreement with previous studies (Caldwell, 1968).

Six stratigraphic cross sections were constructed within the study (illustrated by figure 2) based on detailed electric log analysis of the Bearpaw Formation. The sections establish correlation to a type locality described by Given and Wall (1971), illustrate the distribution and geometry of the Bearpaw sediments and describe the vertical and lateral changes in the lithology in the formation.

Three cross sections (figures 6, 7, and 8) run east to west in Townships 36 (figure 6), 30 (figure 7), and 25 (figure 8) in a direction normal to regional strike.

Three north-south sections along Range 2 W 5 (figure 9), Range 22 W 4 (figure 10) and Range 19 W 4 (figure 11) complete the grid of cross sections which illustrate the progressive thinning of the Bearpaw Formation to the west, north and northwest by the transitional change of the Upper Shale Unit and the Middle Shale Unit into sands of the overlying Horseshoe Canyon and the First Castor Sandstones, respectively.

IV. DEPOSITIONAL CYCLES

> "... during the Late Cretaceous Epoch, ... movements of land and sea are recorded in the sedimentary sequence, which broadly, between the Rocky Mountain foothills of Alberta and the plains of eastern Saskatchewan and Manitoba, is cyclic and composed of marine, brackish-water, and fresh-water clays, silts, and sands" (Caldwell, 1968, p.1).

If the strand line remains stable for a sufficient period of geologic time and environmental conditions permit, the formation of lignite and coal may occur.

The Bearpaw Formation as encountered in the subsurface of the study area, consists of six depositional cycles of coarsening-upward sequences of clastics that range from clay to sand size. Coal seams tend to occur mainly above sandy to silty beds near the top of a cycle. Only the fine phase of the uppermost cycle was considered, as the coarse fraction was considered to be the basal unit of the overlying Horseshoe Canyon Formation, and the unit is referred to as the Upper Shale Unit. The other five cycles in ascending order are referred to as cycles A, B, C, D, and E (figure 12).

Cycle A

The lower part of this cycle is mainly shale and silty shale with sand lenses in the middle part of the interval. This part of the Bearpaw Formation is transitional from the underlying Judith River Formation, and sand lenses probably grade laterally into the underlying formation. Figure 13 illustrates the thickness distribution of this unit and

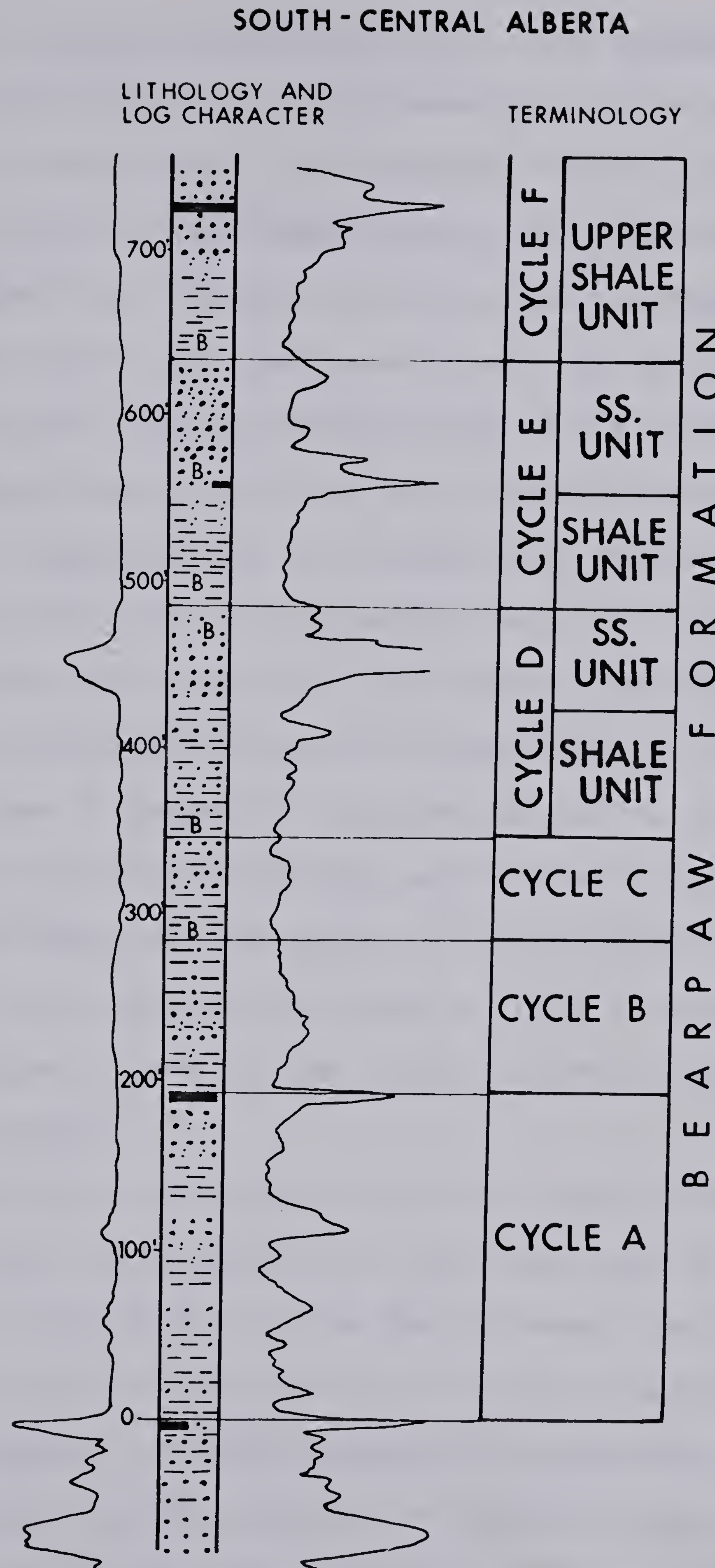


Figure 12. Depositional Cycles, Bearpaw Formation, South Central Alberta.

indicates its widespread distribution. It is somewhat irregular in distribution and thickens to a maximum of 200 feet along the central part of the area, with thicker areas trending in a north to northeast direction indicating the center of deposition. The unit thins to the northwest to about 100 feet and to the southwest where the thickness is 70 feet. A similar trend is encountered in the northeast and southeast respectively, with the variation possibly explained by irregularities in the basin of deposition inherent from the Judith River surface on which the sediments of this basal unit of the Bearpaw Formation were deposited. The distribution of the lower unit in the western part of the area is probably explained by facies change relationships with the underlying Judith River sands. Areas where the lower part of the cycle is thin probably represent areas closer to the Judith River delta front whereas thicker sections represent areas farther from the delta front and deeper into the sea.

It is difficult to explain the thinning of this lower unit to the east and southeast in the study area in terms of a transgression approaching from the southeast as inferred for the advance of the Bearpaw Sea. The only explanation that would probably fit the thickness distribution in that part of the area, is the presence of highs in areas of lessened thickness or perhaps the basin of deposition was shallower in these localities. Williams and Burk (1964) showed two sources for clastics of the underlying Judith

River Formation, one from the southwest and one from the northwest, and Stelck (1975, p.438) referred to the effect of the Sweetgrass arch in deflecting the sediments "... somewhat to the lows on either side ..." of the arch, and, "... it retained the coarser clastics within the old Precambrian basinal areas." It follows that during the deposition of the lower unit of cycle A the Sweetgrass arch probably affected its thickness distribution, as much as the local irregularities on the Judith River.

The upper part of this cycle grades from the lower shaly unit and forms the first coarsening-upward sequence in the Bearpaw Formation. It consists of siltstone that grades into a sandstone towards the top, commonly with interfingering between shaly sands and silty shales. Coal is present within the sandy zone and can be traced for considerable distances within the area. The top of the sand represents a sharp contact with the overlying unit and is used as the datum for the cross sections because of its wide distribution in the area. The lower contact of the sandy zone tends to be gradational with the underlying shaly part of the cycle and is difficult to determine an exact boundary.

The distribution of the sandy, upper part of cycle A is illustrated by figure 14. The sand is thickest in the west, where more than 140 feet are encountered, and thins to the east where it is less than 10 feet thick. Four major east-west trending thick areas with intervening thin areas

are apparent on the map (figure 14). The area of thick sediments in the north thins to the southeast in the form of lobes separated by thin areas that trend northwest - southeast. The remaining areas of thick sediments in the central and southern part occur in the form of radial patterns originating from the west. Thicker sand distribution takes the form of elongate lobes that are separated by areas where the thickness is less than 20 feet (figure 14). The linearity of features in figure 14 could be potentially caused by three factors. The first factor is probably the selection of control points along east-west lines and no attempt could be made to investigate this possibility due to the poor quality of borehole electric logs between the control points used in the study. The other two factors are depositional processes and tectonic influences and these will be discussed in forthcoming chapters.

The following observations follow from the distribution of cycle A on the stratigraphic cross sections and isolith maps (figures 6 to 11, 13 and 14):

1. Cycle A represents a coarsening-upward sequence of deposition. Clay (or shale) grades up into interbedded clay and silt or very fine sand.
2. Sheet and channel sands probably form the coarse fraction of the cycle and are widespread over the area.
3. The total thickness of the cycle varies from 100 to 240 feet.

4. Coal is present above sands in a number of wells and individual beds can be traced for several miles.

Moreover, the sandy zone of cycle A is very thick in the west along the trends seen in figure 14. From the south, the first trend is thickest (132 feet) in Lsd. 10, Sec. 24, Twp. 25, Rge. 2, W. 5 Mer., and spreads to the east in four thick lobes, only one of which continues for any distance to the east, maintaining a thickness of 100 feet in the center of the trend. A thickness of 97 feet is encountered farther east in Lsd. 6, Sec. 1, Twp. 27, Rge. 15, W. 4 Mer., which indicates the continuity of thick distribution after which the sand becomes progressively thinner to the north, northeast, and southeast.

North of this trend, another body of similar thickness abruptly thins to the east in the vicinity of Rge. 1, W. 5 Mer., where its distribution is overtaken by a third lobe coming from the northwestern part of the area. This latter lobe, more than 140 feet thick, extends from the northwest towards the south and southeast in two trends that continue to the east.

Only part of the most northern distribution is included in the study area. The interval is thicker in the north and northwest and thins to the south and east. It appears that the sandy zone is more northerly oriented than its counterparts in the central and southern parts of the map area. However, there is little doubt that both sands are

equivalent, although a more northerly source area might be suggested for the interval in the north.

Facies change explains the variation in thickness of the sandy zone as it replaces the clays and silts in a westerly direction so that the lower unit of this cycle is relatively thin in the west below the thick trends of the sandy part of the cycle.

Only the top 34 feet of this cycle are included in the basal beds of the "Lower Shale Unit" of Given and Wall (1971) in the Castor well, which accounts for the sandy zone and part of clays and silts beneath the sand in the cycle. The interval as described from core by Wall (1971), consists of 28 feet of medium to dark grey shales interbedded in the lower 14 feet with occasional silt laminae, plant remains and few bentonite layers in the middle of the core. The upper 14 feet of the core contains similar shales, but differ from the lower interval by the appearance of prominent lenses and stringers of silt and sand in the upper seven-foot interval.

Cycle B

This unit also forms a coarsening-upwards sequence yet spans a smaller interval than the underlying cycle and probably represents a sequence that was interrupted at the time of deposition. The lower contact of cycle B is well defined in most well logs by a sharp decrease of resistivity (deflection to the left), and a noticeable increase of spontaneous potential (deflection to the right), seen in

figures 6 to 12. The upper contact is difficult to determine due to the abrupt changes in facies of the top part laterally across the area.

The unit consists of a lower shale and an upper silty interval interbedded with silty sandstone at the top. It is well defined and traceable in the southeastern part of the area and particularly along section CC′ (figure 8). The thickness of the unit is 110 feet in Lsd. 10, Sec. 9, Twp. 25, Rge. 19, W. 4 Mer., and it can be divided in ascending order into a lower 40 foot shale, a middle 60 foot siltstone and a 10 foot silty sandstone. Along section DD′ the upper contact of this cycle is placed at the top of the silty sandstone interval, which is overlain by the basal shales of cycle C. The fine fraction of this unit, represented by the shales at the base, progressively thins to the west in Lsd. 6, Sec. 11, Twp. 25, Rge. 3, W. 5 Mer., where it is approximately 25 feet thick and is underlain by a sandy bed that probably originated from the west as a shoreline facies, perhaps extending from the underlying sandy zone of cycle A.

The shale also decreases in thickness to the north (figure 7) where it is approximately 30 feet thick in the eastern part of the section, and is interbedded with silt in the western part of the section. The shale is not well defined further north along section AA′ (figure 6) especially in the Castor well, and the adjacent well to the west where the apparent thickness of the shale is about 15

feet or less. Silt replaces the shale to the west along section AA′ and the shale is not more than a few feet thick in the far west of the section.

The overlying silty interval thins gradually from the east along section CC′ and becomes sandy from Lsd. 11, Sec. 20, Twp. 25, Rge. 22, W. 4 Mer. to Lsd. 6, Sec. 11, Twp. 25, Rge. 3, W. 5 Mer. Similar conditions occur along section DD′ to the north where the interval loses its characteristic appearance on the logs in Lsd. 11, Sec. 18, Twp. 30, Rge. 21, W. 4 Mer. and is replaced by sand from that position to the western part of the section. Farther to the north, along section AA′, the silty interval becomes sandy and difficult to correlate with the rest of the area and is included in the silty sandstone and sands of the overlying part of the cycle.

The uppermost part of cycle B is a silty sandstone which was rather difficult to correlate across the area as it is relatively thin. It defines the contact between this cycle of deposition and the overlying shale. It is mainly apparent along section CC′ where it thickens to the west to a maximum of 40 feet, largely replacing the underlying silty interval. This replacement is also seen along section BB′ (figure 7) in Lsd. 12, Sec. 26, Twp. 30, Rge. 25, W. 4 Mer., where a noticeable coarsening-upward unit is more apparent and where a coal seam overlies the sandy interval. A similar situation exists along section AA′ (figure 6) where the silty sand is overlain by a silty interval with a 3 foot

coal seam at the top. The coal is apparently not present east of Rge. 22 W. 4 Mer. in section AA′, east of Rge. 23 W. 4 Mer. on section BB′ and along section CC′. The sandy interval is difficult to trace to the northeastern corner of the area and only the top of the underlying silt can be seen on section AA′.

Cycle B is represented in the Castor well by a 35 foot interval of shale which contains lenses of silt and fine-grained sand in the lower half and thin sandy intervals in the upper half. The sandy shale intervals described are not greater than one foot thick and are most probably a continuation of their counterparts described in cycle C.

East of Rge. 22, W. 4 Mer. the top sandy and silty interval of cycle B changes to silty shales and shales. The cycle become fining-upwards in grainsize as illustrated by the type log (figure 5) and the stratigraphic sections, and this represents a facies change of the top of cycle B to the east in the area of study.

Cycle C

This cycle forms the third coarsening-upward sequence in the Bearpaw Formation and is similar to the underlying unit in thickness. It consists of a lower shale interval, which is overlain by a silty and sandy interval which is in turn overlain by a coal seam at the top. The unit is best illustrated in the western part of the area along sections AA′, BB′, and CC′. The log signature is well represented in Lsd. 11, Sec. 20, Twp. 25, Rge. 22, W. 4 Mer. on section CC′

where the unit is 67 feet thick. To the east, the coal seam is replaced by a sandy bed that continues to the eastern part of the section with a slight carbonaceous content as reflected by dfferences in the shallow and deep resistivity curves. The silty nature of the shale decreases slightly to the east also. West of Twp. 25, Rge. 22, W. 4 Mer. on section CC′ the shale becomes progressively more silty with prominent sandy interbeds. Although this cycle is much thinner than cycle A, it reflects a similar lithologic character as portrayed by the log signature.

Individual components of this unit have similar distribution to the components of cycles B and A along section AA′ and, the pinching out of the coal takes place at almost the same locality as the coal seam of cycle B (east of Rge. 22, W. 4 Mer.). This change occurs slightly farther west along section BB′ (east of Rge. 25, W. 4 Mer.).

Correlation of this interval with the Castor well is shown by section AA′ where this interval is equivalent to beds from 90 to 160 feet above the base of the Bearpaw Formation in that well. There the shales are more silty and sandy grading into the upper part of the unit with an increase in sandy interbeds. The sands are greenish, glauconitic, fine grained, generally bentonitic and occasionally contain shell fragments. A sandstone, fine to medium grained, non-calcareous, with kaolinitic cement was described 7 feet below the top by Given and Wall (1971).

Cycle D

This succession is easily recognized by a general coarsening-upward in grain size distribution in Lsd. 10, Sec. 9, Twp. 26, Rge. 17, W. 4 Mer. along section CC′ and represents an important part of the Bearpaw Formation. The lower two thirds of cycle D is equivalent, in the northeastern part of the area, to the upper part of the 'Lower Shale Unit' of Given and Wall (1971), and the upper one third of the cycle is equivalent to their "Second Castor Sandstone" member.

In the southeastern part of the study, the lower two thirds of this cycle consist mainly of 50 feet of bentonitic shales, and silty shales that grade upwards into 40 feet of interbedded sandstones and silty sandstones in the middle part. The middle succession grades upwards into a shaly interval approximately 40 feet thick below the base of the overlying Second Castor sandstone equivalent which constitutes the upper third of the cycle.

Further subdivision of this cycle to the northwest and west of this locality (Twp. 26, Rge. 17, W. 4 Mer.) is necessary as the one cycle character is no longer apparent. A two cycle division of this unit can be seen in that part of the area along all cross sections. The lower cycle, also a characteristic coarsening-upward sequence, consists of bentonitic shales at the base that grade upward into silty shales, and finally towards the top sandy beds appear and are overlain by a coal seam that attains a thickness of 4

feet. The upper cycle consists of the 40-foot shaly interval and the overlying second Castor sandstone that formed the upper part of the cycle in the east.

Lower Sub Cycle: The upper part of this cycle is characterized by the presence of a coal seam at the top of the succession, and is similar in distribution to cycles B, and C. The lower silty shales of this unit change laterally to the west into silty sands and sandstone with thin beds of clays. Shales thin to the west and are completely replaced by silt and sand interbeds (figure 7), that continue upwards to replace the remaining part of the lithology in the cycle. Thus the coal seam distribution is limited between Rge. 22, W. 4 Mer. and Rge. 19, W. 4 Mer. in figure 6, and extends farther west in figure 7, and is limited between Rge. 25, W. 4 Mer. and Rge. 20, W. 4 Mer. in figure 8.

The Upper Sub Cycle: The unit consist of a lower shale interval and an upper sandy interval that consists of silty sands and sands that are equivalent to the Second Castor Sandstone of Given and Wall (1971). The cycle is widely distributed over the area and averages 100 feet in thickness. As the underlying coal seam is not recognizable west of Rge. 25, W. 4 Mer. (figure 8), both the lower and upper cycles merge to form one cycle as the intervening shale of the upper cycle thins to the west.

The upper part of this cycle is a prominent sandstone that has been described in the northeastern part of the study by Given and Wall (1971). The sandstone is 34 feet

thick and is greyish-green in color. It is medium-grained, glauconitic and has a non-calcareous kaolinitic cement. The lower part of the sandstone is slightly argillaceous and contains bentonitic laminae. The upper part of the sandstone is cleaner and has a fair porosity as reflected by the log signatures (figures 6 to 11).

The log signature of the sandstone in the area of study reflects the presence of clay, as the resistivity decreases within the interval and the spontaneous potential increases towards the shale line. The fair porosity zone indicated in the Castor area is not as simple to correlate, but can be indicated in those wells where the spontaneous potential deflection is considerably more negative than it is for the lower argillaceous part of the sandstone.

From the different cross sections (figures 6 to 11), the Second Castor Sandstone equivalent is illustrated to spread widely over the area, with minor variations. Along section AA′ the sandstone is continuous to the west and thickens to more than 70 feet as the lower cycle is replaced by sands, and is more than 100 feet thick farther to the west. The upper limit of the sand is difficult to interpret as the overlying shale of cycle E is not present west of Range 25 west of the Fourth Meridian along this section. A similar condition prevails along sections BB′ and CC′ where the upper boundary of the sandstone is not clear west of Range 1 and 2 west of the Fifth Meridian.

The distribution of the Second Castor Sandstone

equivalent is illustrated in figure 15. From south to north, five major thickness accumulations (enclosed by the 100-foot isolith) can be seen. Thickness concentrations are elongate lobal features radiating from the west. Each accumulation has its own network of lobate extensions radiating from the main sand body. All the accummulations have a central thick distributional trend that thins to the north, south and east of the main body. Only four of the main sand bodies continue across the area to the east. The maximum thickness attained is 158 feet in the west (Lsd. 10, Sec. 22, Twp. 26, Rge. 1, W. 5 Mer.). The maximum width of the lobate distributions is approximately 12 miles.

The systems of thick distribution are separated by areas where the sandy unit is relatively thinner, and transitional into lateral facies. The sandy unit is widely distributed over the area and thins to the east yet is present in all the wells studied and, the 25-foot isolith is inferred in the eastern part of the area.

Cycle E

This unit represents the fifth major coarsening-upward sequence in the Bearpaw Formation and appears to have a paleogeographic significance as will be discussed in later chapters. It is easily identified by a two-fold division into a lower shale unit and an upper sandstone unit. The two units are correlative with the Middle Shale Unit and the First Castor Sandstone of Given and Wall (1971) and are widely distributed in the area of study.

The lower shale unit has an average thickness of 80 to 90 feet in the eastern part of the area and thins gradually to the northern, northwestern and western parts of the area. It is generally bentonitic and silty with lenses of silt throughout most of the interval in almost all the well logs studied. The presence of silt in the lower shale unit is also indicated by Given and Wall (1971) in their core description. The silt fraction is dominant in the basal part of the shale and the thickness of silty interbeds decreases in the middle and increases towards the upper part of the shale. Their description is in close agreement with the interpretation of the log signature of the present study.

The distribution of the shale member of the cycle is also illustrated in figures 6 to 11 and figure 16. In the northern part of the area (figure 6) a gradual decrease in thickness of the shale unit is clearly apparent from the well logs, until finally the shale pinches out to the west of Range 25 West of the Fourth Meridian. Consequently the contact with the overlying First Castor Sandstone is stratigraphically lower in the west than it is in the east as the lower beds of the overlying sandstone replace the shale. The decrease in thickness of the shale is 73 feet from the Castor well to the wells in the west, a distance of approximately 72 miles. A similar situation exists along section BB', but the shale extends farther west to the vicinity of Rge. 1 W. 5. The decrease in thickness is approximately 100 feet in about 84 miles (figure 16). A

similar trend is illustrated by section CC′ where the shale unit is less than 30 feet in the extreme western part of the section.

Figure 16 illustrates the distribution of the shale unit of cycle E in the area of study. The shale increases in thickness to the east and southeast in the area. Areas where the shale is thin are elongate and lobate in pattern, and are separated by areas where the shale unit increases in thickness. The zero isolith represents the western limit of distribution of the shale unit, and the 150 foot isolith is tentatively drawn where the unit reaches its maximum thickness in the area of study.

The upper part of cycle E is transitional from the underlying shale unit and consists of a sandstone interval which is equivalent to the First Castor Sandstone of Given and Wall (1971). As described by Given and Wall, the sandstone interval is silty at the base and contains bentonitic shale laminae. The silty beds are overlain by a medium-grained, non-calcareous 39-foot sandstone with bentonitic and rare carbonaceous lenses and laminae. This sandstone interval is calcareous in places and has a kaolinitic cement. It is overlain by a 6-foot medium to coarse-grained sandstone interval which is grey and grey-green in color with bentonitic laminae and occasional carbonaceous lenses. The overlying 7-foot interval is a coarse-grained sandstone which is moderately glauconitic. It contains only few bentonitic laminae and carbonaceous

stringers, and has fair porosity. Overlying this unit, the uppermost 5-foot sandstone interval is medium to coarse-grained, strongly glauconitic in the upper foot, with kaolinitic cement, and buff colored clay beds. The upper contact of the First Castor Sandstone is placed at the base of an overlying bentonitic shale.

This sandstone interval was correlated into adjacent wells in the area on the basis of its stratigraphic position and log signature and was found to extend over much of the area. The lower boundary of the sandstone can be traced westerly to the pinchout of the underlying shale unit in the western part of sections AA′ and BB′. West of that position it is difficult to establish the lower boundary and the two sandstones (First and Second Castor) join to form one continuous sandstone interval. The intervening shale unit between the two Castor sandstones extends further west along section CC′ as discussed earlier and thus the lower boundary of the First Castor Sandstone is well established along the southern edge of the study area.

The upper contact of the sandstone is determined by the base of the overlying Upper Shale Unit and the distribution of that unit is limited to the eastern part of the area (discussed in the next section). Thus the top of the sandstone can only be traced (at least by this study) east of the zero isolith of the overlying Upper Shale Unit. West of that position the sandstone merges with the lower sandstones of the overlying Horseshoe Canyon Formation and

it is difficult to determine the top of the sandstone in that area. Intervals of the sandstone become extremely carbonaceous to the west of that locality indicating a facies change and transition from the sandy nature of the interval in the east. According to Lines (1963), the sandstone is 30 feet thick northeast of the Castor well, and is described as a bentonitic, white weathering, typical non-marine sandstone. Lines (1963) believed that lithologically the sandstone is similar to higher Horseshoe Canyon sands (Edmonton Group), but included it with the Bearpaw succession.

Along section BB′ (figure 7) the sandstone is considerably thicker in the west than it is in the eastern part of the section especially when its upper limit becomes difficult to interpret, beyond Range 22 west of the Fourth Meridian. A similar distribution of the sandstone is illustrated by section CC′ (figure 8).

Distribution of the First Castor sandstone is illustrated by figure 17. The sand is present in the eastern part of the map area between Range 15 and 23 west of the Fourth Meridian. The sand isoliths trend somewhat similar to the lower shale unit (figure 16), with a different location of thin and thick areas of sandstone distribution.

Six major areas are illustrated by the map, where thicker lobate sandstone bodies extend from the west to the east. These trend to the southeast in the southern part of the map and occupy a position that coincides with areas of

thin distribution of the shales underlying the First Castor Sandstone, and a similar comparison, yet in reverse, exists for the areas where the sand is thin. A change to a more easterly trend takes place in the thick sand lobes further north in the central and northern parts of the map area, with radiating distributary lobes and fingers of sands branching from the main sand body. Farther north a more northeasterly trend is recognized.

Upper Shale Unit

This represents the uppermost succession in the Bearpaw Formation and is part of yet another coarsening-upward sequence recognized in the study area. It is underlain by the First Castor Sandstone and overlain by the basal beds of the Horseshoe Canyon Formation. The lower contact is somewhat gradational from the top of the sandstone in places and sharp in others. The upper contact of the unit is also gradational and intertongueing with the overlying basal Horseshoe Canyon beds (figures 6-11). The unit is described in the Castor well (Given and Wall, 1971), where it consists mainly of shale which is medium to dark grey in color. The shale contains bentonitic, silty laminae and disseminated carbonaceous material at different intervals of the core. A similar distribution of lithologies is correlated from the well logs of the area of study. Furthermore the shale unit contains sandy tongues that can be shown to pinch out to the east (figures 8 and 11).

As illustrated by the stratigraphic cross sections, the

shale unit pinches out to the west between Lsd. 1, Sec. 32, Twp. 36, Rge. 20, W. 4 Mer. and Lsd. 10, Sec. 22, Twp. 36, Rge. 19, W. 4 Mer. (figure 6) and, between Range 23 and 21 west of the Fourth Meridian (figure 7) and west of Range 23 west of the Fourth Meridian (figure 8). The pinchout position is indicated by the zero isolith in figure 18, with the shale unit absent to the west of that line. The shale interval thickens to the east and southeast in the area of study where it attains a thickness of 150 feet.

The Upper Shale Unit is thinner in the north than it is in the south and south-east, as illustrated by the north-south trending sections (figures 10 and 11). Its thickness is 90 feet in the southern part of section FF′ and thins to the north and west by successively losing the upper beds of the unit by facies change into the Horseshoe Canyon basal beds.

The overlying member of this cycle is similar in lithology and log signature to the sand and coarse fraction of the previously discussed cycles D and E, and in addition contains wide spread coal seams that attain considerable thickness. The base of this sandstone and carbonaceous interval is considered as the upper boundary of the Bearpaw Formation in the study area.

V. LOCAL AND REGIONAL INFERENCES

A. Relation to Castor Area

Lines (1963) proposed a two member subdivision for the Bearpaw Formation from outcrop sections along the Battle River and on Paintearth Creek, about 15 miles northeast and north, respectively, of the Castor well. The Young Creek Member consists of 220 feet of argillaceous sandstone and shale marked at the base by a few chert pebbles. Two sandstone beds, each about 50 feet thick were described from this member. The overlying Paintearth Member consists of 180 feet of alternating dark shale and massive sandstone, and the base of the member is marked by a chert pebble bed 3 feet thick. Two 30-foot sandstones were reported by Lines from this member. The lower sandstone was believed to be the equivalent of the Bulwark Sandstone of Slipper (1919) and was reported to be fairly widely distributed in southcentral Alberta (Lines, 1963). Given and Wall (1971) correlated the Bulwark Sandstone and another sandstone interval below the top of the Bearpaw Formation (described as non-marine by Lines), to the Second and First Castor Sandstones respectively on the basis of lithologic similarities and electric log character. It follows on the basis of lithology and electric log character that the Paintearth Member of Lines (1963) is equivalent to those beds in the area of study (including the First and Second Castor Sandstones) that lie between the top of the Bearpaw Formation and the

base of the shale unit below the sandstone of cycle D. Thus the sandstone intervals of cycles D and E are equivalent to the Bulwark Sandstone and the upper "non-marine" sand of the Paintearth Member respectively (table 1).

The upper sandstone interval of the Young Creek Member is probably equivalent to the sandy interval of the lower part of cycle D, and the lower sandy interval of the member is probably the equivalent of the sandy zone of cycle B. The lower shale unit of the Young Creek Member seems to be equivalent to the lower shale unit of cycle B, which would probably indicate that cycle B is more developed to the northeast, outside the study area.

B. Relation to Red Deer River Section

The sections of the Bearpaw Formation exposed near Dorothy comprise approximately the upper 225 feet of the formation (Given and Wall, 1971). The sections are located in Sec. 26 and 33, Twp. 26, Rge. 17, W. 4 Mer., and Sec. 28, Twp. 27, Rge. 18, W. 4 Mer. and are included within the area of study (table 2). According to their stratigraphic position and lithologic character the components of the sections described are related to the present study as follows:

1. The dark blue-grey shale and the overlying 20-foot thick, brownish-grey, glauconitic "Dorothy sandstone" (informaly named) of the section are most likely equivalent to the upper sequence of cycle D which

	THESIS AREA		GIVEN & WALL, 1971.	LINES, 1963.
	HORSESHOE CANYON FM.		HORSESHOE CANYON FORMATION	HORSESHOE CANYON FORMATION
BEARPAW FORMATION	CYCLE F	UPPER SHALE UNIT	UPPER SHALE UNIT	
	CYCLE E	SANDSTONE UNIT	FIRST CASTOR SANDSTONE	unnamed s.s. unit; PAINTEARTH MEMBER
		SHALE UNIT	MIDDLE SHALE	
	CYCLE D	SANDSTONE UNIT	SECOND CASTOR SANDSTONE	" BULWARK " SANDSTONE
		SHALE UNIT	LOWER SHALE UNIT	
	CYCLE C	SANDSTONE		YOUNG CREEK MEMBER
		SHALE UNIT		
	CYCLE B	SANDSTONE UNIT		
		SHALE UNIT		
	CYCLE A	SANDSTONE		
		SHALE UNIT		BELLY RIVER FORMATION
	JUDITH RIVER FORMATION		BELLY RIVER FORMATION	

Table 1. Relation of outcrop sections and core of the Bearpaw and adjacent Formations in Castor area to the subdivisions of the present study.

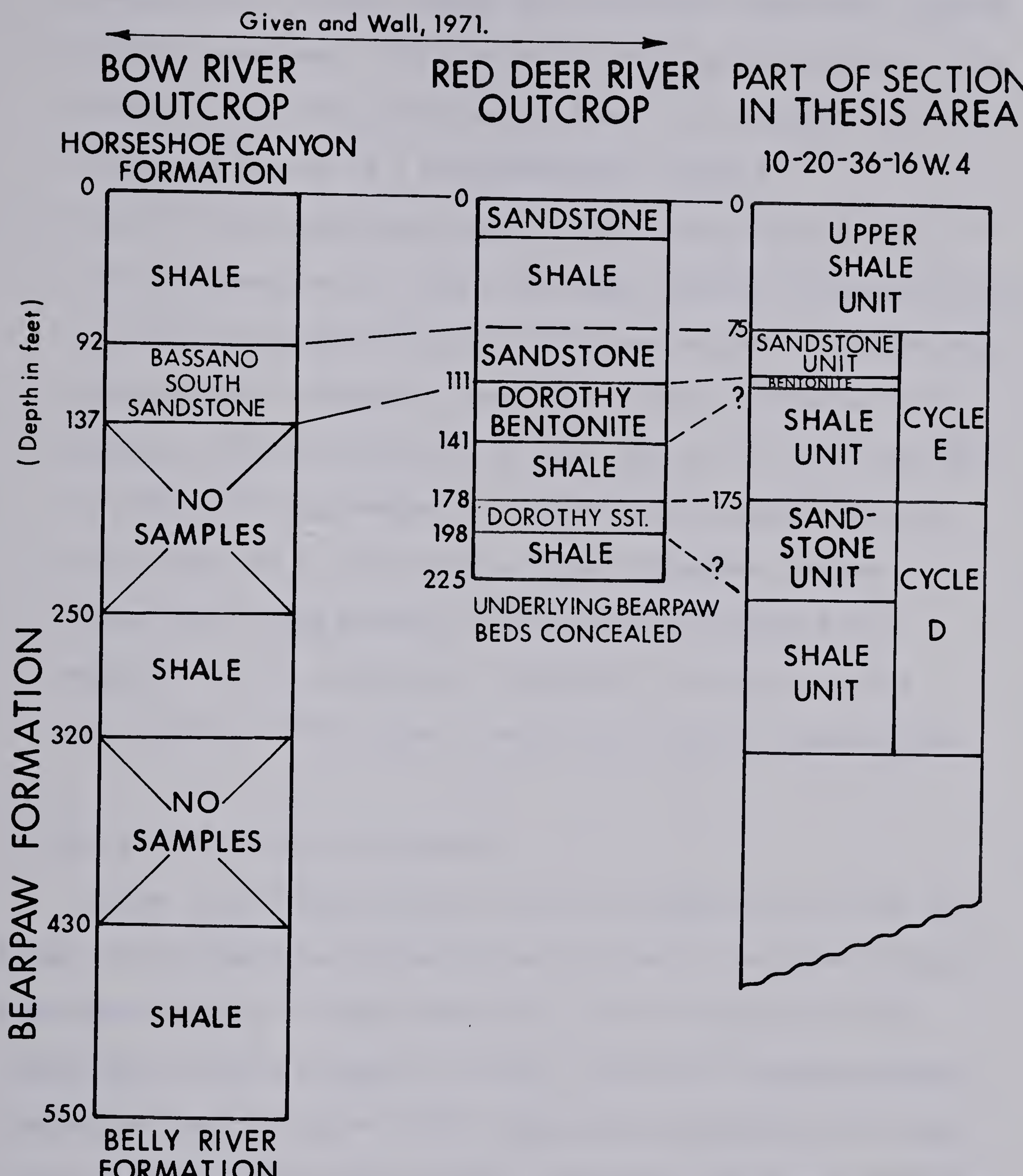


Table 2. Relation between Red Deer River and Bow River outcrop sections to part of the subdivision of the present study.

consists of a lower shale unit and the overlying Second Castor Sandstone. This relationship is established from correlations along the eastern part of section FF′ (figure 11) and is illustrated by table 2.

2. The 35-foot arenaceous shale, the overlying 30-foot "Dorothy bentonite", and the sandy base of the overlying 111-foot of brownish-grey silty shale that contains some carbonaceous fragments are most likely equivalent to cycle E. The silty shale at the top is in turn overlain by shale and succeeded by interbanded sandstone and siltstone, with the base of the Horseshoe Canyon Formation being placed at the bottom of the first massive thick sandstone. The shale interval is the equivalent of the Upper Shale Unit earlier described.

C. Bow River Outcrop Sections

Clark (1931) described a 40-foot sandstone on the Bow River in the Bearpaw Formation which he called the "middle sandstone Member". Given and Wall (1971) consider this sandstone to be the same as their informal "Bassano South Sandstone" which Clark (1931) apparently placed at a lower stratigraphic position. Another interval, the Bassano Member of Russell (1950) and Russell and Landes (1940), in the area between the town of Hanna and the Little Bow River is described as consisting of finely banded, brown sandy shales and clayey sandstone. The interval lies in the upper part of the Bearpaw Formation, and is overlain by the basal member

of the Edmonton Formation (equivalent to Horseshoe Canyon). The lower part of the member seems to be correlative with the "Bassano South Sandstone" of Given and Wall (1971), and from the present study it can be deduced that it is correlative with the First Castor Sandstone of cycle E that also continues to the south and is most likely equivalent to the Bassano South Sandstone (table 2).

D. Regional Inferences

Figure 19 tentatively illustrates the relationships between the Bearpaw of the present study area and its counterparts in southern Alberta and southwestern Saskatchewan.

Cycle A of this study seems to be equivalent to part of the lower one third of the Lethbridge section with the addition of the Magrath sandstone. The interval is probably the equivalent of part of the lower one third of the Manyberries Member of the Cypress Hills and the Demaine and Sherrard Members of the south Saskatchewan River valley.

Cycles B, C and D are probably equivalent to the Kipp sandstone and the underlying shales of the Lethbridge section and to the Ardkenneth Sand and Beechy Shale Members of Saskatchewan and to the middle part of the Manyberries Member of the Cypress Hills.

The shale unit of cycle E (Middle Shale Unit of Given and Wall, 1971) is probably equivalent to the shales overlying the Kipp Sand of the Lethbridge section. This unit

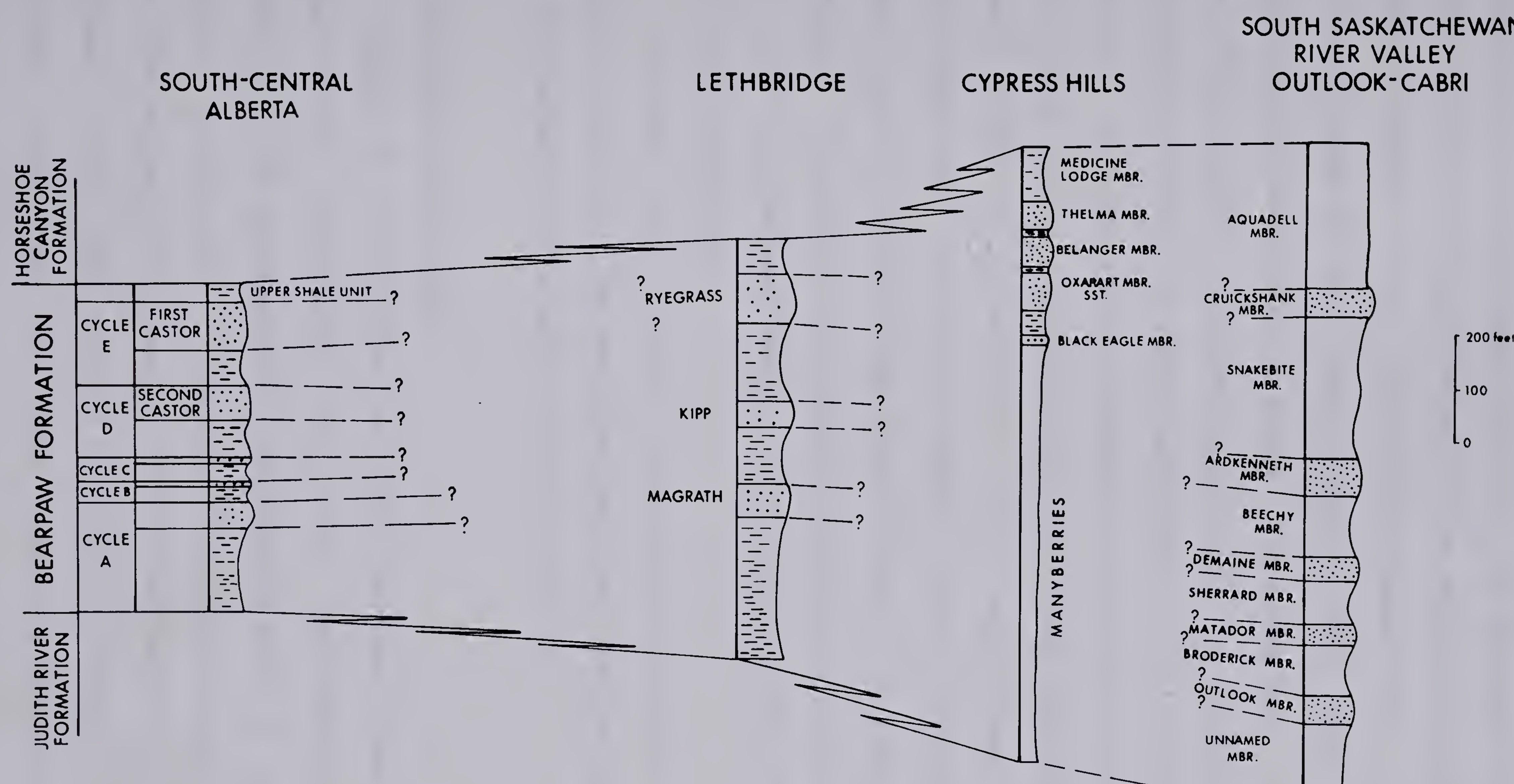


Figure 19. Lithologic correlation of the Bearpaw Formation between the area of study, Southern Alberta and Southwestern Saskatchewan.

is correlative to the upper part of the Manyberries Member of the Cypress Hills and which is the equivalent of the Snakebite Member of the south Saskatchewan River valley as was established by North and Caldwell (1970) from foraminiferal and ammonite zones. The sandy unit of cycle E (i.e. First Castor Sandstone equivalent) is probably the correlative of the Rye Grass Sandstone of the Lethbridge section. This sandstone is probably equivalent to the lower part of the Oxarart Sandstone and the Black Eagle Member of Russell (1950) in Cypress Hills. North and Caldwell (1970) established that the Oxarart Member and the Cruikshank Member are in the *Baculites eliasi* Zone. It follows that the sandy unit of cycle E is probably equivalent to the lower part of the Cruikshank Member of the south Saskatchewan River valley section.

The Upper Shale Unit of the Bearpaw Formation is present in most of the sections and overlies the sands that are equivalent to the upper part of cycle E.

E. Thickness Variations

Figure 20 illustrates the total Bearpaw Formation isopach within the present study area. The formation is thickest in the southeastern and eastern part of the area and thins to the north, northwest and western part of the area. The maximum thickness of the formation in the southeast is 696 feet and the minimum thickness in the northwest is 300 feet. The upper sandstone intervals of the

Bearpaw Formation (cycles D and E) considered as part of the Horseshoe Canyon Formation in the northwestern part of the area.

Thickness of the formation at Castor is 470 feet (Given and Wall, 1971) and to the south it is 575 feet (figure 20). Further south the formation thickens to 740 feet at Keho Lake (Clark, 1931) and at Lethbridge a thickness of 726 is reported (Link and Childerhose 1931). The formation thickens to the east to 1030 feet in southwestern Saskatchewan (Loranger and Gleddie (1953) and it is 900 feet thick in the south Saskatchewan River valley (Caldwell and North 1964).

To the northwest the Bearpaw Formation thins to a thickness of 100 feet according to data from well logs in the Pembina field west of Edmonton (Williams and Burk 1964). West of the area of study only cycles A to C and the lower part of cycle D might be present north of the Bow River, but it would be very difficult to recognize the shales as part of the Bearpaw Formation as they become extremely silty and sandy as illustrated by section DD′ (figure 9). This is probably why the formation is reported to be absent in that part of the west in Alberta (Williams and Burk 1964).

VI. DEPOSITIONAL ENVIRONMENT

Data from which this part of the study is derived is based on the interpretation of the results of the present study, and on the results of forminiferal studies of Given (1969) and Given and Wall (1971) in the Castor area, Anan-York (1969) in the Lethbridge area, on a study by Shepheard and Hills (1970) relating to the depositional environment of the transition zone in the upper part of the Bearpaw Formation southeast of Drumheller, and on the results of studies by Caldwell (1968) and North and Caldwell (1970, 1975) on the formation in the South Saskatchewan River valley.

A. Fluctuation in Water Depth

Figure 21 illustrates the probable environment of deposition of the Bearpaw Formation in southcentral Alberta as interpreted from lithology (thesis area) and from correlation with the results of foraminiferal studies in Castor (Given, 1969 and Given and Wall, 1971) and Lethbridge (Anan-York, 1969) areas. The study area is between Castor and Lethbridge and thus a similarity in the depositional environment of the Bearpaw Formation in the three areas can be expected.

These authors used the dominance of calcareous over arenaceous foraminifera as an indicator of open marine or sublittoral environment of deposition and indicated that the

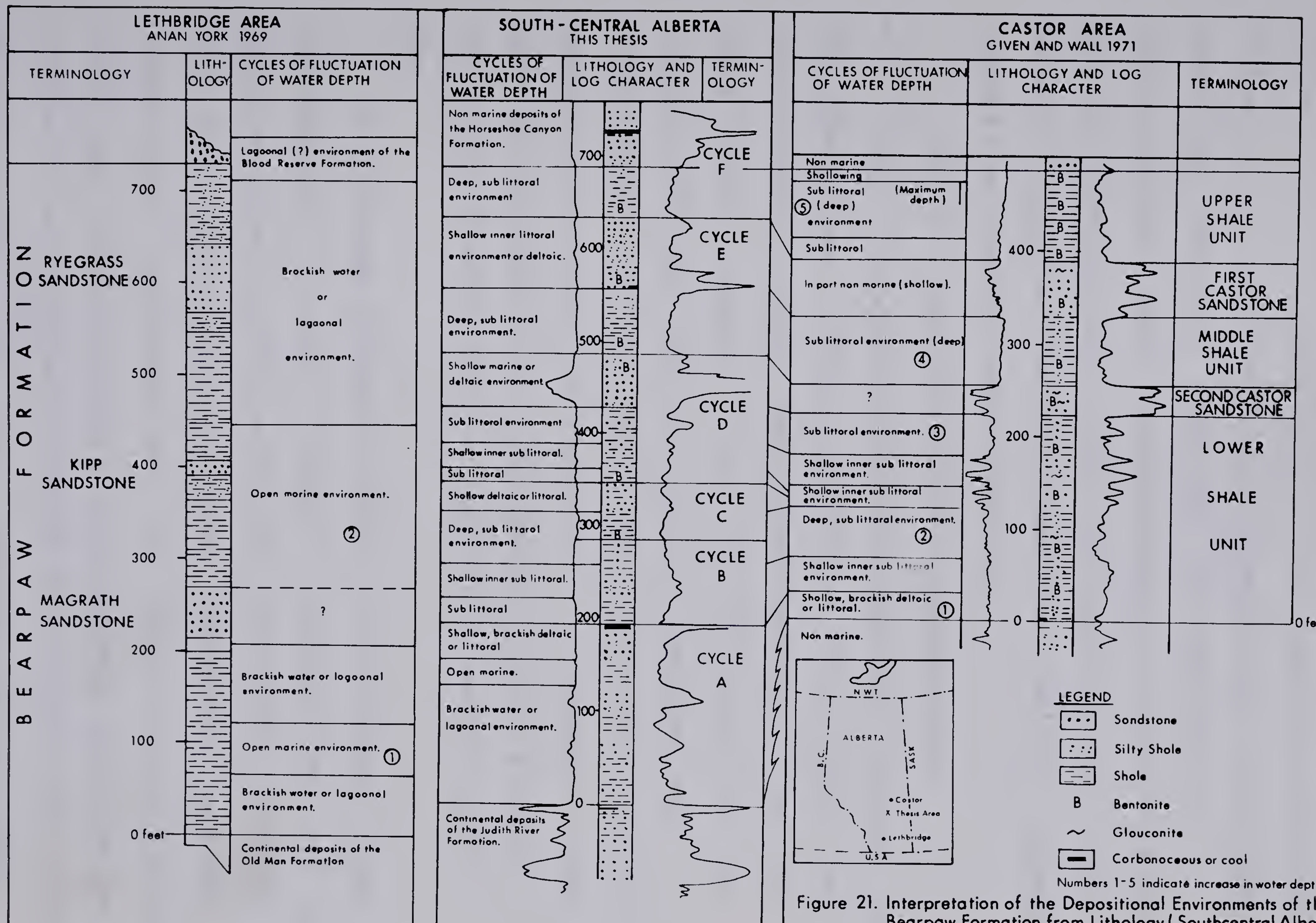


Figure 21. Interpretation of the Depositional Environments of the Bearpaw Formation from Lithology (Southcentral Alberta) & from Foraminiferal Population (Lethbridge & Castor Areas).

absence of calcareous foraminifera would reflect shallower marine or littoral conditions. On this basis two intervals of open marine conditions were suggested from the Bearpaw in Lethbridge (Anan-York, 1969) and five intervals of increasing water depth from the Formation in Castor (Given, 1969 and Given and Wall, 1971). The remaining part of the formation suggested shallower conditions (deltaic, lagoonal, littoral or brackish water conditions).

A similar interpretation of the depositional environment of Bearpaw sediment is suggested from grain size distribution and lithologic variations (this study). The shale intervals suggest open marine conditions, the silty shale intervals suggest a transition from sublittoral to slightly shallower conditions and the sandstone and carbonaceous intervals suggest inner sublittoral to deltaic conditions of deposition (figure 22). An increase in water depth is reflected by a fining-upward in grain size and shallowing is reflected by a coarsening-upward in grain size.

As indicated previously cycle A of the present study is represented by the basal 34 feet in the Castor Well and is deposited under brackish or deltaic conditions (Given and Wall, 1971). At Castor this interval represents the first inundation of the Bearpaw Sea. This interval is represented by 200 feet of shale and part of the Magrath Sandstone and is correlative to cycle A although sand lenses occur in the lower two thirds of the cycle. The shale below the upper

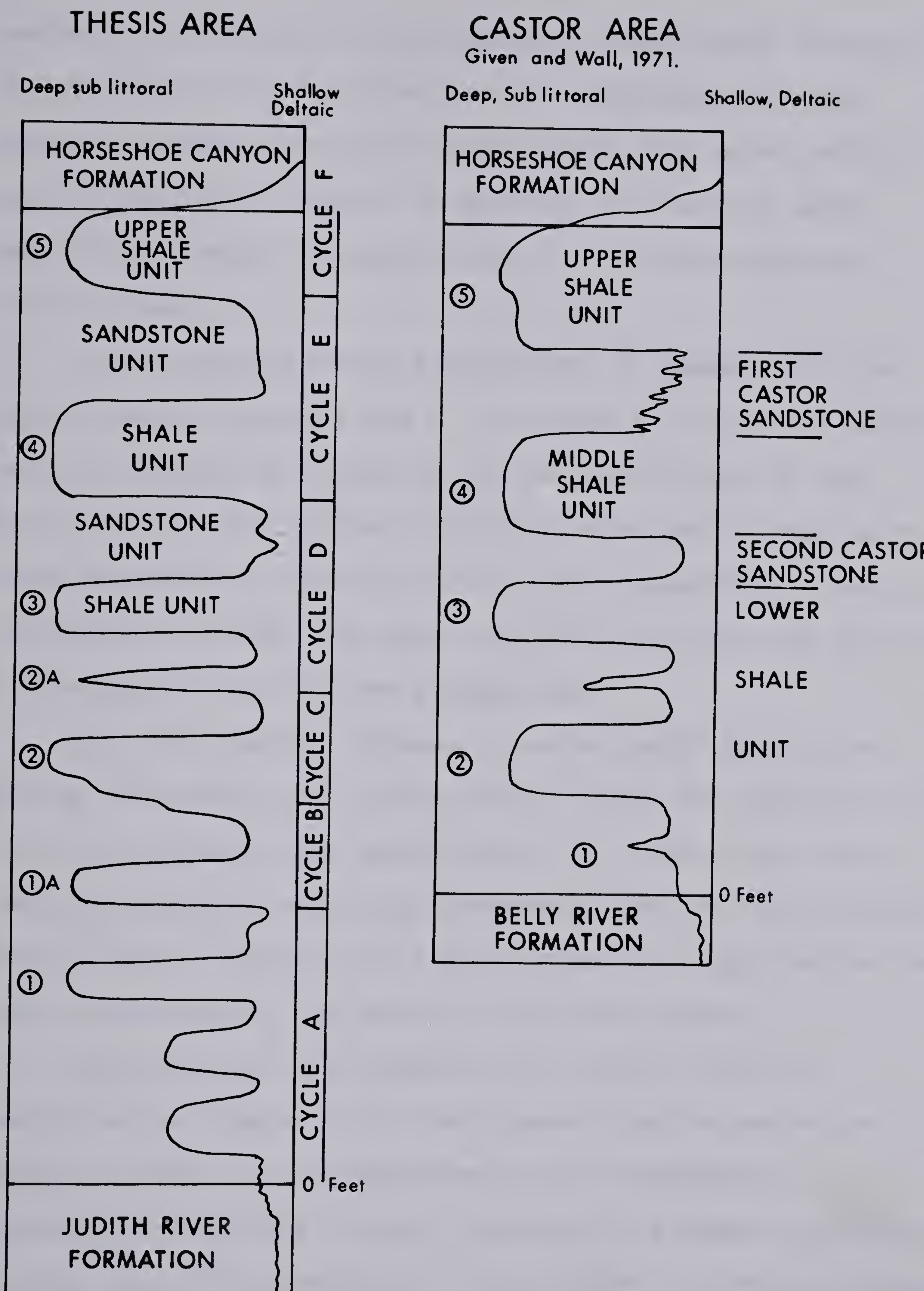


Figure 22. Fluctuation of water depth during the deposition of the Bearpaw Formation in Castor and south-central Alberta.

sandy unit of cycle A is equivalent to the shale interval in the lower part of the formation in Lethbridge that was deposited under open marine conditions. The upper part of cycle A reflects a return to deltaic or brackish water deposition similar to conditions in the Lethbridge and Castor areas.

A similar pattern of fluctuation is repeated by the deposition of cycles B and C. The second increase of water depth at Castor is reflected in the thesis area by the deposition of the shales of cycle C after which shallowing occurred and the sands of cycle C were deposited. This was followed by a minor increase in water depth and the shales at the base of cycle D were deposited.

The third major increase in water depth took place during the deposition of the shales below the sandstone of cycle D (Second Castor equivalent). At Lethbridge, marine conditions prevailed during the deposition of these shales and at Castor a sublittoral environment is suggested by the third deepening of the waters of the Bearpaw Sea.

Deposition of the sandstone of cycle D and its equivalent at Castor took place under shallow marine or deltaic conditions as indicated by the presence of carbonaceous material in the interval in a number of wells in the area. This sandstone is equivalent to the Kipp member in Lethbridge which was deposited under open marine conditions.

The fourth increase in water depth is represented by

the deposition of the Middle Shale unit in Castor area and by the shale unit of cycle E in the thesis area and by the shales below the Rye Grass Sandstone member in the Lethbridge area.

Return to shallow inner littoral conditions took place during the deposition of the sandstone of cycle E, the First Castor Sandstone (Castor area) and the Rye Grass Sandstone in Lethbridge.

The fifth major inundation by the Bearpaw Sea deposited the Upper Shale Unit at Castor, the shale unit of cycle F in southcentral Alberta and the shale overlying the Rye Grass Sandstone at Lethbridge. The maximum depth reached by this inundation took place during the deposition of the shale 10 feet below the top of the Bearpaw formation in the Castor well as indicated by Given and Wall (1971).

Therefore five major increases in water depth are suggested during the deposition of the Bearpaw Formation in southcentral Alberta. Two additional minor increases in water depths are suggested for the shale interval of cycle B and the basal shales of cycle D, as illustrated by figure 21. The two minor fluctuations are represented in the Castor area by thin shale intervals that were deposited under shallower conditions, and by a shale interval in Lethbridge that was deposited under open marine conditions.

B. Cyclicity

A repeated pattern of deposition can be recognized in the three areas discussed above and at least three types of deposits are seen within the sequence of Bearpaw sediments in southcentral Alberta. A somewhat deep sublittoral deposit is illustrated by interbedded shales and silts that constitute the fine fraction of each cycle. A shallower littoral or deltaic deposit is illustrated by interbedding of sands and silts of the coarse fraction of the cycle, where the distribution of sandstone could possibly imply the effect of current activity. Finally the coal seams and carbonaceous deposits and their underclays are indicative of even shallower swampy environment of the cycle.

The repetition of the cycle is demonstrated completely by cycles A, D, E, and F of the study and partially by cycles B and C that were interrupted either by decrease in sediment supply or increase in water depth. This cyclicity is also illustrated in the Castor and Lethbridge areas by repeated alternations of littoral and sublittoral deposits as illustrated by the absence or presence of calcareous foraminifera.

Cyclicity is also persistent in the transition zone below and above the boundary of the Bearpaw and Horseshoe Canyon Formations. Shepheard and Hills (1970) investigated the environment of deposition of the transition zone ten miles southeast of Drumheller in Alberta. Their study concentrated on the uppermost part of the Bearpaw Formation

and the lower part of the Horseshoe Canyon Formation and thus included the sandstone of cycle E and the Upper Shale Unit of the present study. According to their findings the deposition of the sediments of the transition zone was associated with the movements of a shoreline eastward across southern Alberta and that likely a series of deltaic complexes existed along the margin of the sea in front of a broad coastal plain. Six cycles of characteristic deposits were illustrated by their study with each sequence of sediments being deposited within a particular part of the delta environment. In particular their unit "BP" which is equivalent to the Upper Shale Unit "... resembles very closely the prodelta and delta front deposits of most of the modern deltas deposited offshore of the subaerial portions of the deltas" (Shepheard and Hills, 1970, p.199). The prodelta deposits are fine grained with dominant structures being laminae and thin interbeds of silt and shale in the Mississippi Delta (Fisk, 1961). The remaining five cycles of Shepheard and Hills (1970) are in the lower part of the Horseshoe Canyon Formation and consist of distributary channel and marginal channel deposits, beach-barrier complex, open bay mud flat deposits and open bay deposits. One important sequence, that of the distributary channel and marginal channel deposits consists of major distributary sand deposits overlain by clays and silts of the marginal swamp and back-swamp deposits and finally coals of the marsh deposits are found at the top of the sequence. Lateral

gradation of the deposits of this sequence is indicated by Shepheard and Hills (1970) and a similar gradation is also persistent between the shales of the unit "BP" and the sands of unit "E1".

C. Cycle A

The present study has illustrated the distribution and geometry of this cycle and the results are now discussed in relation to environmental implications.

The lower shale unit of cycle A is predominantly wedge-shaped and is thick in the east (200 feet) and thin in the west (70 feet) in southcentral Alberta. The unit is not present to the northeast of the area and probably grades laterally into the upper beds of the Belly River Formation in the Castor area. The unit is characterized by the presence of laminae of silt interbedded with the shale and occasional silty sandstone interbeds. The presence of silt laminae within the shale is similar to the prodelta and delta front deposits of modern deltas described by Fisk (1961) and Coleman and Gagliano (1964) in the Mississippi deltaic complex. The lower shale unit of cycle A grades upwards into siltstone and silty sandstones that grade into a sandstone bed towards the upper part of the cycle. This coarsening-upward is also another characteristic of modern deltaic deposits prograding in a seaward direction. Further progradation is illustrated by the presence of clay and the overlying coal seam at the top of cycle A which resemble

deposits of the swamp and marsh environment of modern deltas.

The sandstone of cycle A is thicker in the west (closer to the source) where more than 140 feet are encountered, and thins out to the east where it is less than 10 feet thick. It is distributed along four major eastwest trending thick areas (figure 14) that thins to the east and southeast in the form of lobes. This distribution is similar in areal extent with the distribution of channel deposits and their complex distributaries and that of the thin areas resembles sheet-like deposits of the interdistributary area. The channel sands are probably similar in distribution to bar finger sands and silts of the Mississippi delta (Fisk, 1961) but have a more complex trend of distribution that probably indicates more active shifting of streams during deposition.

D. Cycle E

This unit represents the fifth major coarsening-upward sequence in the Bearpaw Formation and consists of a lower shale unit and an upper sandstone unit. The lower shale unit is generally bentonitic and silty with lenses of silt throughout most of the interval across the area of study. The presence of silt is also indicated by Given and Wall (1971) in their core description. The dominance of silt is recognized in the basal beds of the unit, decreases in the middle part of the shales and increases again in the upper part of the shale interval. This distribution of the silt

indicates a slow incoming transgression from the east that increases during the deposition of the middle part of the shale interval where the silt fraction is not dominant and then a return to prodelta shales and silts during the deposition of the upper part of the shale interval. This pattern of deposition is further illustrated by the geometry of this unit, typically wedge-shaped, and thinning to the north, west and southwest of the study area.

The base of the sandstone of cycle E is silty and contains shale laminae that grade upwards into a 39-foot sandstone which is medium grained and contains occasional carbonaceous lenses. This is overlain by an 18-foot sandstone interval that also contains carbonaceous stringers. Carbonaceous stringers become more persistent in the western part of the area and this is associated with a thicker distribution of the sandstone interval (figure 8). The sandstone is distributed along six major thick trends separated by areas where the sandstone is thin and sheet like in distribution (discussed earlier). The sandstone distribution within the thick trends along with the coarsening-upward character of the deposit resembles a similar pattern of deposition as the sandstones of cycles A and D and strongly suggests a relation to bar finger sands. The presence of carbonaceous lenses and stringers suggests shallowing and shifting of streams and the existence of marsh environment. Caldwell (1968) indicated the presence of wood fragments (of all sizes) imbedded into the sands of the

Bearpaw Formation of the Saskatchewan River valley and other types of plant fragments, and indicated that deposition of the formation took place under shallow water conditions, and that the clays were deposited at no greater depth than the sands. Caldwell adds (page 66) "... The clays are anything but "pure" clays, and the great bulk of them contain a high profusion of silt ... 35 to 45 per cent silt."

E. Conclusion

The information presented in this study show that cyclicity is an important factor in the deposition of the Bearpaw Formation in southcentral Alberta and neighbouring areas. The cycles are similar in gross features such as lithology, grain size distribution and geometry with a dominant coarsening-upward character. The shale units of the cycles are wedge-shaped and contain a high proportion of silt grading vertically and laterally into the coarser sandy part of the cycles. The sandstone units of the cycles, their character, distribution and areal extent indicate the predominance of stream activity in their deposition. The study also illustrated that carbonaceous lenses and coal seams with a lagoonal clay beneath are present at the top of cycles A, C, D, E and F of the formation.

These findings illustrate that the cycles of the Bearpaw Formation were deposited under shallow marine deltaic conditions similar (with slight variation) to deposits of the Mississippi delta (described by Fisk, 1961).

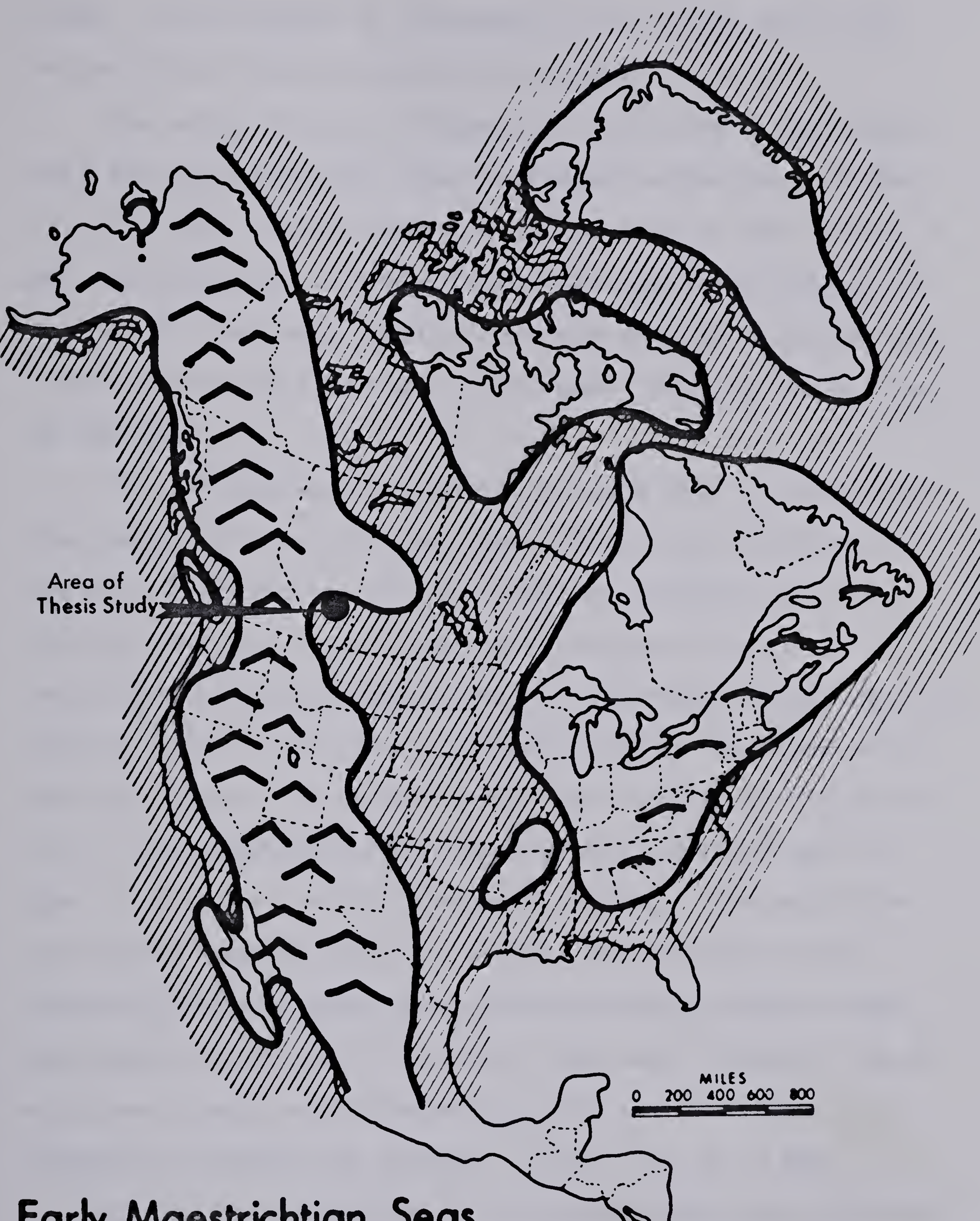
This environment persisted during the deposition of the unit "E1" of the lower part of the Horseshoe Canyon Formation of Shepheard and Hills (1970). The fine fraction of the cycles represent prodelta and delta front shales and silts and the coarse fraction respresents bar finger sands and sheet sands of the distributary mouth bar and interdistributary sediments of the delta complex. Moreover deltaic lobe progradation with avulsion and compaction should be considered as mechanisms for the cyclicity of the Bearpaw sediments in the study area.

VII. PALEOGEOGRAPHY

The last major transgression during the Late Cretaceous (late Campanian to early Maestrichtian) time penetrated Alberta north of the Peace River arch (Wall, 1973, 1975), and as far west as the edge of the foothills in southern Alberta and Montana (Williams and Stelck, 1975), (figure 23), depositing the Bearpaw Formation. Maximum flooding took place in Alberta at the time of *Baculites reesidei* (Rosene, 1972) in the latest Campanian. This is also the case in the Rocky Mountain states (McGookey *et al*., 1972). A connection is suggested between the western interior, Greenland and Europe from close affinities of *Scaphites quadrangularis* (which occurs in the *B. reesidei* zone) to eastern forms (Jeletzky, 1971a; Birkelund, 1965).

Sedimentary infilling of the basin from the west perhaps with accompanying uplift of the Mackenzie Mountain region (Williams and Stelck, 1975) forced the sea to retreat from the interior of the continent. The record of this transgressive and regressive sequence in the sediments discussed in the present study indicates the shoreline position, or at least the shoreline phase, in southcentral Alberta.

Figure 13 indicates that the first inundation by the Bearpaw Sea reached a position close to the foothills region, but probably not further west than Rge. 8, W. 5 Mer. in the south and probably not further west than Rge. 10, W.



Early Maestrichtian Seas

B. baculus time

Figure 23. Map showing extent of early Maestrichtian seas at the time of Baculites baculus (adapted from Williams and Stelk, 1975).

5 Mer. in the north, as indicated by the sandy and silty nature of the shale interval of cycle A.

The sandy interval (figure 14), of cycle A indicates that the shoreline must have regressed to the east of Rge. 17, W. 4 Mer. in the south and to the east of Rge. 19, W. 4 Mer. in the north as suggested by the coal seam present at the top of the sandy interval and the deltaic progradation illustrated by the extension of trends into the eastern part of the map.

The intermediate pulses of cycles B and C indicate two fluctuations illustrated by their similar distribution to cycle A. Distribution of the prodelta shales of cycle D indicate two more intertonguing transgressions and regressions. The transgressions did not reach as far west as the previous inundations as illustrated by the sandy nature and thinning of the shales to the west and north (figures 6 to 11). The shoreline position probably remained east of Rge. 4, W. 5 Mer. within the area of study. The shoreline was forced back and shallow lagoons formed within the interdistributary areas and swamps advanced towards areas previously occupied by the shore. Coal was formed on top of silts and sands and the waters of the sea must have withdrawn, probably to the east of Rge. 19, W. 4 Mer.

During the deposition of the shales below the sands and coals of cycle D, the water came back well into the region west of Rge. 1 W. 5 Mer. but probably not too far west of that position as the shales become silty and sandy along

section DD′ (figure 9).

The filling up of the basin during the deposition of the Second Castor Sandstone pushed the sea back to the east gradually, just west of the most eastern deltaic branches shown in figure 15.

The sea again transgressed over the area as shown by the shales of cycle E in figure 16 as far as the zero isolith line that runs across the area in a northeast to southwest direction. After the basin filled up and the First Castor Sandstone was deposited, the sea retreated to the east close to Rge. 19, W. 4 Mer. (figure 17), a final transgression of the sea over the area produced the sediments of the Upper Shale Unit.

The Upper Shale Unit represents the prodelta shales and silty shales of the final transgression of the Bearpaw Sea (figure 18), with the zero isopach line east of Rge. 22, W. 4 Mer. where the unit pinches out representing the shoreline position. As the deltaic deposits of the Horseshoe Canyon prograded to the east the sea was pushed back to the east and south of the area. The regression was gradual and the main direction of retreat appears to be slightly to the southeast as reflected by the orientation of the isolith lines of the Upper Shale Unit.

The paleogeography of the area during the deposition of the Bearpaw was dominated by pulsating shoreline conditions that were affected by deltaic deposition, with sediments supplied rapidly from the west and deposited into a slowly

subsiding basin. If the rate of sediment supply and water discharge are constant and relatively high during a period of time then long linear sand bodies are common and build progressively in a seaward direction (Coleman, 1976). Another factor that can be suggested for the long linear trending sand bodies of cycle A is the probable presence of linear structural east-west trending channel features. These channel features might have affected the direction of progradation of the deltaic cycles of the Bearpaw Formation in the study area.

VIII. CONCLUSION

Six cycles of deltaic deposits are suggested for the Bearpaw Formation in southcentral Alberta and neighbouring areas. In ascending order the cycles are named A, B, C, D, E and the Upper Shale Unit. Each cycle consists of a coarsening-upward sequence (shale, silts and fine to medium grained sandstones) that represents a gradation from prodelta shales at the base to silts and sands of the delta front and distributary mouth bar facies. Coal is present at the top of cycles A and C, and the lower part of D. Carbonaceous stringers are present at the top of the sands of cycle E, and in the middle of the sands of cycle D. The presence of coal is indicative of shallow lagoonal or marsh and swamp environments of the delta.

Interruption of the cycles such as B and probably C and the sharp contact at the top of the cycles (especially A and D) indicates by comparison with faunal evidence that deeper conditions prevailed and the sea transgressed over the area. Seven pulses of transgressive nature are interpreted to have occurred during the Bearpaw depositional history as suggested from the presence of an additional cycle in cycle D (considered as one cycle as both join and are not recognized in the north and west as separate).

As the depth of water is interpreted to be close to 150 feet (Caldwell, 1968), infilling of the basin forced the waters of the Bearpaw Sea to retreat to a more easterly

position, and deltaic subenvironments prograded vertically on previously deposited ones to form the characteristic coarsening-upward sequence.

Detailed correlations indicate that the lower contact between the Bearpaw Formation and the underlying Judith River Formation rises to the west and is diachronous, as the top beds of the Judith River gradually replace the basal beds of the Bearpaw Formation. In detail the contact is strongly interfingering as seen in well logs.

The Bearpaw Formation is much thinner in the northwest (300 feet) than it is in the southeast (695 feet), with the decrease caused by gradual thinning of the shale units to the northwest and the pinching out of the two shale units above and below the First Castor Sandstone.

The seven pulsating transgressions of the Bearpaw Sea indicate that the paleogeography was unstable and fluctuating. Environmental variations that are present in the sediment record above the Bearpaw Formation indicate that the climate was humid and sub-tropical, perhaps like that of the Mississippi Delta area in the Gulf Coast at present (Shepheard and Hills, 1970). A close similarity was found between the transition zone above the Upper Shale Unit and Bearpaw sediments, suggesting that a similar interpretation is reasonable for the depositional environment of the Bearpaw Formation.

The upper boundary of the Bearpaw Formation has been described as diachronous by many authors. As suggested by

evidence from this study (thinning of sand units to the east and south, and facies change in the upper part of the formation) the Bearpaw Formation of southcentral Alberta grades laterally and vertically upwards into the Horseshoe Canyon Formation and that the upper boundary of the Bearpaw Formation is older in the southeast than it is in the northwest in the study area.

SELECTED BIBLIOGRAPHY

Allan, J.A., and Sanderson, J.O.G., 1945, Geology of Red Deer and Rosebud sheets, Alberta: Alberta Research Council Report, Rept. 13, pp. 1-52.

Anan-York, R. 1969, A microfaunal study of the Bearpaw Formation, Lethbridge area, Alberta: Unpubl. M.Sc. thesis, Univ. of Alberta, Edmonton.

Birkelund, T., 1965, Ammonites from the Upper Cretaceous of West Greenland; Medd. Om Gronland, Vol. 179, No. 7, Copenhagen, 192 pp.

Caldwell, W.G.E., 1968, The Late Cretaceous Bearpaw Formation in the South Saskatchewan River Vally, Saskatchewan Research Council, Geology Division, Report No. 8, pp. 1-86.

——————, and North, B.R., 1964, Foraminiferal faunas in the Cretaceous, Montana Group of southwestern Saskatchewan: Third International Williston Basin Symposium, pp. 143-151.

Clark, M.C., 1931, Sections of Bearpaw Shale from Keho Lake to Bassano southern Alberta: Am. Assoc. Petrol. Geol., Bull., Vol. 15, Pt. 2, No. 10, pp. 1243-1249.

Cobban, W.A., and Reeside, J.B. Jr., 1952, Correlation of the Cretaceous Formations of the Western Interior of the United States: G.S.A., Bull., Vol. 63, pp. 1011-1044.

Coleman, J.M., 1976, Deltas: Processes of Deposition and Models for Exploration, Louisiana State Univ., Continuing Education Pub. Co., Inc.

——————, and S.M. Gagliano, 1964, Cyclic sedimentation in the Mississippi River deltaic plain: Gulf Coast Assoc. Geol. Soc. Trans., 14: 67-80.

Crockford, M.B.B., 1949, Oldman and Formost Formations of southern Alberta: Amer. Assoc. Petrol. Geol., Bull., Vol. 33, No. 4, pp. 500-510.

Dawson, G.M., 1883, Report on the region in the vicinity of the Bow and Belly Rivers, North-West Territory, Canada, Geol. Survey, Report of Progress (1880-81-82), Pt. B.

——————, 1884, Report on the region in the vicinity of the Bow and Belly Rivers, North-West Territory, Geol. and Nat. History Survey and Mus. Canada, Rept. Progress (1882-1884) p. 1C-169C, Dawson Bros., Montreal.

Dowling, D.B., 1917, The southern plains of Alberta: Canada, Geol. Surv., Mem. 93.

Eicher, D.L., 1967, Depth in the Greenhorn Sea, in, A Symposium on Paleoenvironments of the Cretaceous Seaway in the Western Interior, Colorado School of Mines, Golden.

Elliott, R.H.J., 1960, Subsurface correlation of the Edmonton Formation: Alberta Soc. Petrol. Geol. Jour., Vol. 8, pp. 324-337.

Feniak, M.W., 1944, Athabasca-Barhead map-area Alberta (summ. account), Canada, Geol. Survey, Paper 44-6.

Fisk, H.N., 1961, Bar-finger sands of Mississippi Delta; *in* Peterson, J.A., and Osmond, J.C., (eds.) Geometry of sandstone bodies, Forty-fifth Annual Meeting, Symposium, Amer. Assoc. Petrol. Geol., Tulsa, pp. 29-52.

Folinsbee, R.E., Baadsgaard, H., and Lipson, J., 1960, Potassium-argon time scale, Internat. Geol. Congress, XXI Session Rept., Pt. 3, Pre-Quaternary absolute age determination, pp. 7-17.

—————, Baadsgaard, H., and Lipson, J., 1961, Potassium-argon dates of Upper Cretaceous ash falls, Alberta, Canada, New York Acad. Sci., Annals, Vol. 91, Art. 2, Geochronology of rock systems, Pt. 3 - Phanerozoic time scale, pp. 352-363.

—————, Baadsgaard, H., Cumming, G.L., Nascimbene, J., and Shafiqullah, M., 1965, Late Cretaceous radiometric dates from the Cypress Hills of Western Canada, Alberta Soc. Petrol. Geol.; 5th Annual Field Conf. Guide Book, pt. I, pp. 162-174.

—————, Baadsgaard, H., and Cumming, G.L., 1970, Geochronology of the Cretaceous-Tertiary boundary of the Western Plains of North America, Eclogae Geol. Helv., Vol. 63/1, p. 91.

Fraser, F.J., McLearn, F.H., Russell, L.S., Warren, P.S., and Wickenden, R.T.D., 1935, Geology of southern Saskatchewan, Canada, Geological Survey, Mem. 176, pp. 21-24 and 123-126.

Furnival, G.M., 1946, Cypress Lake map area Saskatchewan, Canada, Geol. Surv., Mem. 242, pp. 38-63.

Gill, J.R., and Cobban, W.A., 1966, The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming, U.S. Geol. Surv., Professional paper 393-A, 73 pp.

Given, M.M., 1969, Foraminifera of the Bearpaw Formation central southeastern Alberta, Unpubl. M.Sc. thesis, Univ. of Alberta, Edmonton.

——————, and Wall, J.H., 1971, Microfauna from the Upper Cretaceous Bearpaw Formation of southcentral Alberta, Bull. Canada Petrol. Geol., Vol. 19, No. 2, pp. 504-546.

Harland, R., 1970, Dinoflagillates and acritarchs from the Bearpaw Formation southern Alberta, Unpubl. Ph.D. thesis, Univ. of Alberta, Edmonton.

Hatcher, J.B., and Stanton, T.W., 1903, The Stratigraphic position of the Judith River beds and their Correlation with the Belly River Beds, Science N.S., Vol. 18, pp. 211-212.

Hills, L.V., and Levinson, A.A., 1975, Boron content and paleogeographic interpretation of the Bearpaw and contiguous Upper Cretaceous strata in the Strathmore Well of southern Alberta, *in* Caldwell, W.G.E. (ed.), The Cretaceous System in the Western Interior of North America: Geol. Assoc. Canada, Special paper, No. 13, pp. 411-414.

Jeletzky, J.A., 1968, Macrofossil zones of the marine Cretaceous of the Western interior of Canada and their correlation with the zones and stages of Europe and the Western interior of the United States, Canada, Geol. Surv., Paper 67-72.

——————, 1971, Marine Cretaceous biotic provinces and paleontology of Western and Arctic Canada; illustrated by a detailed study of ammonites, Canada, Geol. Surv., Paper 70-22.

Lines, F.G., 1963, (submitted 1947), Stratigraphy of the Bearpaw Formation in southern Alberta, Bull. Can. Petrol. Geol., Vol. 11, No. 3, pp. 212-227.

Link, T.A., and Childerhose, A.J., 1931, Bearpaw shale and contiguous formations in the Lethbridge and Alberta, Bull. American Assoc. Petrol. Geol., Vol. 15, Pt. 2, No. 10, pp. 1227-1242.

Loranger, D.M., and Gleddie, J., 1953, Some Bearpaw zones in southwestern Saskatchewan and southern Alberta, Alberta Soc. Petrol. Geol., Third Ann. Field Conf. Guide Book, pp. 158-175.

Martin, L.J., 1961, Tectonic Framework of Northern Canada, *in* Geology of the Arctic, *ed*. G.O. Raasch, University of Toronto Press, Toronto.

McGookey, D.P., et al., 1972, Cretaceous System; *in* Mallory, W.W., (ed.), Geologic Atlas of the Rocky Mountain Region: U.S.A. Rocky Mountain Assoc. Geologists, Denver, pp. 190-228.

Mello, J.F., 1969, Foraminifera and stratigraphy of the upper part of the Pierre Shale and lower part of the Fox Hills Sandstone (Cretaceous) north central South Dakota, U.S. Geol. Surv., Prof. Paper 611.

―――――――, 1971, Foraminifera from the Pierre Shale (Upper Cretaceous) at Red Bird Wyoming, U.S. Geol. Surv., Prof. Paper 393-C.

Nauss, A.R., 1947, Cretaceous microfossils of Alberta, Jour. Paleontology, Vol. 21, No. 4, pp. 329-343.

North, B.R., and Caldwell W.G.E., 1964, Foraminifera from the Cretaceous Lea Park Formation in Southcentral Saskatchewan, Sask. Research Council, Geol. Div., Report No. 5.

―――――――, 1970, Foraminifera from the Late Cretaceous Bearpaw Formation in the South Saskatchewan River Valley, Sask. Res. Council, Geol. Div., Report No. 9.

―――――――, 1975, Foraminiferal faunas in the Cretaceous System of Saskatchewan, Canada, Geological Assoc., Special Paper No. 13, pp. 303-332.

Obradovich, J.D., and Cobban, W.A., 1975, A time-scale for the Late Cretaceous of the Western interior of North America, Canada, Geological Assoc., Special Paper No. 13, pp. 31-51.

Ower, J.R., 1960, The Edmonton Foundation, Jour. Alberta Soc. Petrol. Geol., Vol. 8, pp. 309-323.

Reiskind, J., 1975, Marine concretionary faunas of the Upper Bearpaw Shale (Maestrichtian) in eastern Montana and southwestern Saskatchewan, Canada, Geol. Assoc., Special Paper No. 13, pp. 235-251.

Rosene, R.K., 1972, Micropaleontology of the Bearpaw Formation southwestern Alberta Foothills, Unpubl. M.Sc. thesis, Univ. of Alberta, Edmonton.

Russell, L.S., 1939, Land and sea movements in Late Cretaceous of western Canada, Trans. Roy. Soc. Canada, Sec. 4, No. 33, pp. 81-99.

―――――――, 1950, Correlation of the Cretaceous-Tertiary transition in Saskatchewan and Alberta, Bull., Geological Soc. America, Vol. 61, pp. 27-42.

———————, and Landes, R.W., 1940, Geology of the southern Alberta plains, Canada, Geol. Surv., Mem. 221, pp. 73-82.

Sanderson, J.O.G., 1931, Upper Cretaceous volcanic ash beds in Alberta, Royal Soc. Canada Trans., Ser. 3, Vol. XXV, Sec. IV, pp. 61-70.

Shafiqullah, M., Folinsbee, R.E., Baadsgaard, H., Cumming, G.L., and Lerbekmo, J.F., 1964, Geochronology of the Cretaceous-Tertiary boundary Alberta, Canada, XXII International Geological Congress, India, 1964, Pt. III, Proceedings Sec. 3.

Shaw, E.W., and Harding, S.R.L., 1949, Lea Park and Belly River Formations of east central Alberta, Bull. Amer. Assoc. Petrol. Geol., Vol. 33, No. 4, pp. 487-499.

Shepheard, W.W., and Hills, L.V., 1970, Depositional environments Bearpaw-Horseshoe Canyon (Upper Cretaceous) transition zone Drumheller "Badlands" Alberta, Bull., Canadian Petroleum Geology, Vol. 18, No. 2, pp. 166-215.

Slipper, S.E., 1919, Viking gas field. Structure of area, Canada, Geol. Survey Summ. Rept., 1917, Pt. C., pp. 6C-9C.

Stanton, T.W., and Hatcher, J.B., 1905, Geology and paleontology of the Judith River beds, Bull., U.S. Geol. Surv., No. 257.

Stelck, C.R., 1975, Basement control of Cretaceous sand sequences in Western Canada, *in* W.G.E. Caldwell, *ed.*, The Cretaceous System in the Western Interior of North America; Geol. Assoc. Canada Special Paper 13, pp. 427-440.

Wall, J.H., 1973, Diatoms and radiolarians from the Cretaceous System of Alberta - A Preliminary Report, Geol. Assoc. Canada, Program and Abstracts, Ann. Meeting, Saskatoon, May 1973, Saskatoon, p. 49.

———————, 1975, Diatoms and radiolarians from the Cretaceous System of Alberta - A preliminary report, Canada, Geological Assoc., Special Paper, No. 13, pp. 391-410.

———————, Sweet, A.R., and Hills, L.V., 1971, Paleoecology of the Bearpaw and Contiguous Upper Cretaceous Formations in the C.P.O.G. Strathmore Well Southern Alberta, Bull., Canadian Petrol. Geol., Vol. 19, No. 3, pp. 691-702.

Warren, P.S., 1931, Invertebrate paleontology of southern plains of Alberta, Bull., Amer. Assoc. Petrol. Geol., Vol. 15, Pt. 2, No. 10, pp. 1283-1290.

Weimer, R.J., 1961, Spatial dimensions of Upper Cretaceous Sandstones, Rocky Mountain Area; *in* Peterson, J.A., and Osmond, J.C., (eds.), Geometry of Sandstone Bodies, Symposium, Forty-fifth Ann. Meeting, A.A.P.G., Tulsa, pp. 82-98.

__________, and Land, C.P., 1975, Maestrichtian deltaic and interdeltaic sedimentation in the Rocky Mountain region of the United States, Canada, Geological Assoc., Special Paper No. 13, pp. 633-664.

Wickenden, R.T.D., 1932, New species of Foraminifera from the Upper Cretaceous of the prairie provinces, Trans. Roy. Soc. Canada, Ser. 3, Vol. 26, Sec. 4, pp. 85-91.

Williams, G.D., and Burk, C.F., Jr., 1964, Upper Cretaceous, Chapter 12; *in*, Geological History of Western Canada, *eds*., R.G. McCrossan and R.P. Glaister, Alta. Soc. Petrol. Geol., Calgary, pp. 169-189.

__________, and Stelck, C.R., 1975, Speculations on the Cretaceous Paleogeography of North America; *in*, The Cretaceous System in the Western Interior of North America, *ed*., W.G.E. Caldwell, Geol. Assoc. Canada Special Paper 13, pp. 1-20.

Williams, M.Y., and Dyer, W.S., 1930, Geology of southern Alberta and southwestern Saskatchewan, Geol. Survey Canada, Mem. 163.

Yarwood, W.S., 1931, Stratigraphy of Spring Coulee Well, Bull., Amer. Assoc. Petrol. Geol., Vol. 15, Pt. 2, No. 10, pp. 1265-1277.

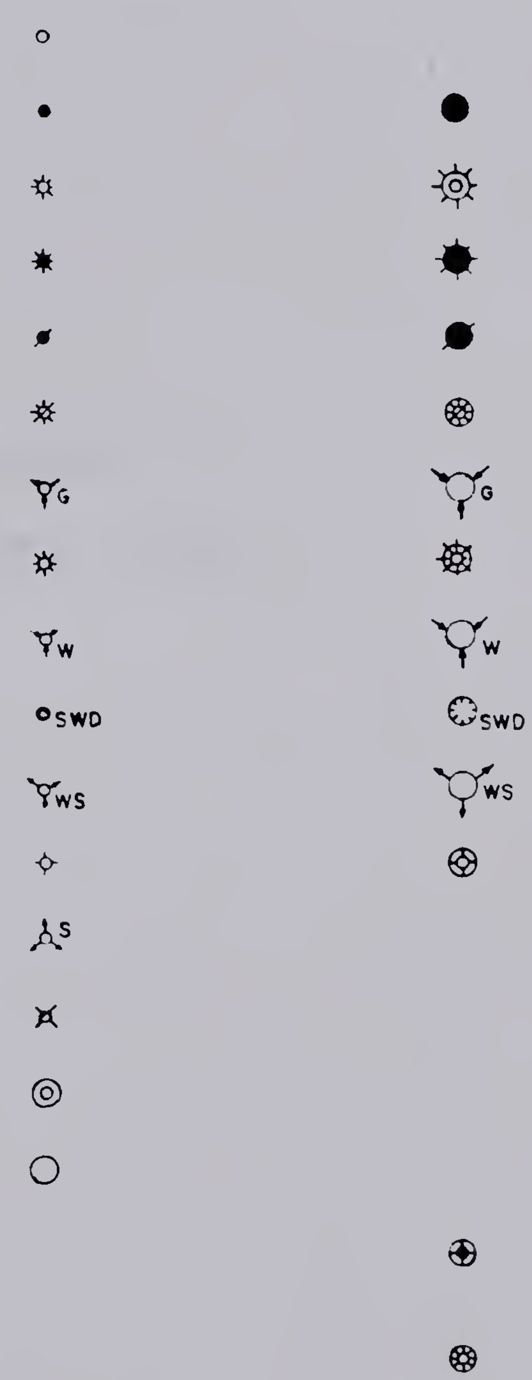
APPENDIX A

Well Standard Symbols

APPENDIX A

WELL STANDARD SYMBOLS

WELL TYPE	POST DEVONIAN	PRE MISSISSIPPIAN
LOCATION		
OIL WELL		
GAS WELL		
OIL & GAS WELL		
ABANDONED OIL WELL		
ABANDONED GAS WELL		
GAS INJECTION WELL		
DUAL GAS WELL		
WATER INJECTION WELL		
SALT WATER DISPOSAL WELL		
WATER SUPPLY WELL		
DRY & ABANDONED		
SALT WATER SUPPLY		
POTASH		
CORE HOLE		
GAS STORAGE		
POST DEVONIAN OIL WELL non productive in pre-mississippian		
POST DEVONIAN GAS WELL non productive in pre-mississippian		



APPENDIX B

Tops Listing

* = concealed by surface casing

E = unit is part of the Edmonton Group

ND = not distinguished

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-09-25-17W4	2843	970	850	729	685	526	426*	*
11-21-25-17W4	2890	1037	916	795	748	590	480*	*
10-28-25-17W4	2877	1057	912	795	750	598	484*	*
10-33-25-17W4	2884	1030	937	818	777	618	505	*
06-13-25-18W4	2945	1131	1004	885	842	683	564*	*
10-15-25-18W4	2943	1142	1016	902	856	702	570	*
10-16-25-18W4	2934	1146	1016	910	874	720	590	490
10-20-25-18W4	3018	1251	1127	1026	956	809	693	593
10-09-25-19W4	3098	1386	1249	1140	1090	930	792	706
12-11-25-19W4	3099	1370	1238	1131	1080	919	784	698
10-13-25-19W4	3084	1343	1216	1120	1059	892	768	685
10-17-25-19W4	3037	1340	1200	1092	1040	869	751	656
06-18-25-19W4	2994	1296	1159	1050	1013	844	726	670
07-14-25-20W4	3039	1340	1244	1143	1096	939	803	760
10-15-25-20W4	2994	1307	1206	1110	1057	908	771	734
06-16-25-20W4	2972	1300	1200	1108	1050	870	758	721
06-18-25-20W4	2982	1409	1244	1132	1070	934	801	773
04-11-25-21W4	3034	1460	1299	1205	1151	975	882	850
14-13-25-21W4	2993	1440	1270	1168	1110	952	848	813
06-14-25-21W4	3089	1516	1370	1266	1207	1056	949	920

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-20-25-21W4	3020	1500	1349	1242	1200	1057	940	930
04-13-25-22W4	2921	1392	1282	1168	1148	998	877	870
10-14-25-22W4	2953	1427	1320	1210	1193	1040	929	920
06-15-25-22W4	2948	1450	1340	1222	1210	1064	960	931
10-16-25-22W4	2951	1481	1360	--	1239.5	1095	990	947
11-20-25-22W4	3220	1877	1662	1607	1540	1405	1279	1262
10-12-25-23W4	2916	1600	1402	1343	1267	1127	1020	990
06-19-25-23W4	3088	1920	1707	1631	1585	1421	E	1341
06-21-25-23W4	3078	1860	1650	1580	1521	1383	E	1291
10-16-25-24W4	3020	1862	1696	1614	1576	1408	E	1344
06-18-25-24W4	3005	1870	1720	1642	1576	1437	E	1360
11-13-25-25W4	2989	1884	1723	1639	1609	1446	E	1381
06-14-25-25W4	3013	1910	1764	1686	1653	1480	E	1420
06-30-25-25W4	3071	2037.8	1911.2	1842	1803	1630	E	1586.9
06-11-25-26W4	3118	2148	2014	1954	1907	1720	E	1680
06-21-25-26W4	3120	2224	2078	2017	1963	1780	E	1740
06-06-25-27W4	3340	2701	2560	2480	2416	2260	E	2214
11-36-25-27W4	3147	2405	2240	2180	2130	1941	E	1900
06-20-25-28W4	3532	3140	2963	2919	2847	2709	E	2680
10-23-25-28W4	3447	2921	2740	2694	2620	2477	E	2439

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-13-25-29W4	3620	3306	3157	3110	3032	2880	E	2850
11-23-25-29W4	3603	3320	3170	3116	3050	2920	E	2880
14-13-25-01W5	3559	3433	3241	3170	3122	2975	E	2940
08-14-25-01W5	3554	3450	3260	3174	3140	2993	E	2970
09-22-25-02W5	4137	4403	4200	4138	4073	3930	E	3915
10-24-25-02W5	3947	4147	3942	3877	3834	3670	E	3660
11-10-25-03W5	3892	4674	4523	4459	4426	4260	E	ND
06-11-25-03W5	3881	4644	4474	4415	4338	4173	E	4116
11-36-25-03W5	4286	4940	4708	4623	4562	4415		
06-27-25-04W5	3985	6212	5060	5000	4951	4799		
06-04-26-17W4	2940	1089	990	869	828	678	550*	*
10-09-26-17W4	2928	1110	992	865	820	667	550	*
06-20-26-17W4	3057	1241	1146	1050	1010	854	731	650
07-13-26-18W4	3057	1270	1170	1056	990	853	739	635
10-18-26-18W4	3135	1398	1304	1214	1170	1002	880	800
11-22-26-18W4	3302	1550	1442	1345	1296	1149	1028	934
10-23-26-18W4	3218	1453	1330	1220	1170	1007	898	810
06-19-26-19W4	3144	1512	1401	1300	1238	1084	940	900
06-20-26-19W4	3203	1591	1460	1359	1300	1140	1013	945
06-21-26-19W4	3245	1589	1488	1385	1330	1191	1040	970

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-26-26-19W4	3316	1617	1541	1447	1393	1232	1105	1041
10-14-26-20W4	3147	1520	1419	1317	1260	1104	960	910
10-15-26-20W4	3122	1513	1392	1305	1243	1080	930	873
07-16-26-20W4	3132	1515	1396	1310	1252	1086	943	905
10-18-26-20W4	3046	1460	1340	1249	1200	1036	870	851
06-13-26-21W4	3053	1486	1380	1282	1234	1073	917	890
10-14-26-21W4	3139	1639	1483	1389	1340	1171	1101*	*
07-15-26-21W4	2982	1416	1324	1230	1182	1020	*	*
06-17-26-21W4	2870	1322	1248	1140	1117	960	760	869
04-18-26-21W4	2840	1407	1239	1127	1110	959	790	850
16-12-26-22W4	2862	1418	1259	1192	1121	974	762	852
10-15-26-22W4	3026	1577	1471	1404	1341	1237	980	1089
07-16-26-22W4	2896	1514	1340	1283	1226	1110	860	960
06-17-26-22W4	2873	1550	1353	1281	1226	1119	850	972
10-09-26-23W4	2814	1594	1396	1332	1284	1156	910	1060
10-11-26-23W4	2855	1529	1394	1307	1270	1114	900	1040
07-12-26-23W4	2851	1546	1364	1298	1249	1086	829	1012
06-16-26-24W4	3008	1917	1754	1675	1637	1490	1300	1438
11-28-26-24W4	3030	1911	1780	1730	1670	1497	1340	1444
10-29-26-24W4	3047	1964	1800	1740	1684	1510	1228	1458

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-30-26-24W4	3117	2020	1866	1819	1760	1620	1300	1565
07-25-26-25W4	3089	2052	1869	1814	1760	1611	1340	1500
10-26-26-25W4	3104	2047	1898	1830	1770	1624	1397E	1565
10-27-26-25W4	3081	2059	1908	1840	1780	1625	1410E	1580
07-28-26-25W4	3126	2082	1924	1866	1819	1663	1415E	1610
10-18-26-27W4	3312	2720	2580	2539	2473	2337	2140	2300
10-22-26-27W4	3168	2551	2378	2328	2276	2125	1939E	2075
06-20-26-28W4	3635	3310	3114	3057	3012	2876	2737E	2830
06-21-26-28W4	3533	3160	2970	2936	2862	2730	2560E	2712
07-09-26-29W4	3562	3452	3260	3203	3140	3010	2865E	2973
11-10-26-29W4	3595	3460	3261	3200	3140	3032	2860E	2984
11-12-26-29W4	3610	3342	3182	3123	3060	2941	2760E	2880
06-24-26-29W4	3633	3408	3219	3156	3090	2969	2760E	2930
18-18-26-01W5	3915	4190	3960	3880	3834	3647	3290E	3560
06-21-26-01W5	3717	3820	3580	3530	3459	3310	E	3410
10-22-26-01W5	3667	3750	3485	3444	3390	3208	3060E	3245
10-24-26-01W5	3574	3527	3320	3253	3194	3060	2938E	3025
07-26-26-02W5	3919	4231	4025	3979	3930	3790	3608	3774
10-34-26-04W5	4268	5560	5293	5239	5157	5020E		5072
06-25-27-13W4	2640	672	580	500	--	--	--	-- *

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
06-08-27-14W4	2647	710	620	533	417	--	--	-- *
06-01-27-15W4	2718	898	678	603	--	--	--	-- *
06-21-27-15W4	2811	934	818	690	612	479	--	-- *
06-25-27-16W4	2903	1034	917	820	749	617	--	-- *
07-28-27-16W4	2970	1184	1039	938	875	740	624	580*
11-31-27-16W4	3061	1290	1166	1076	989	880	765	650
11-20-27-17W4	2620	860	768	677	586	468	--	-- *
11-33-27-17W4	2792	1078	941	850	768	638	521	410
10-26-27-18W4	2653	950	832	750	699	523	--	-- *
10-27-27-18W4	2646	950	841	756	687	534	--	-- *
06-29-27-18W4	2749	1127	978	893	822	--	--	-- *
06-09-27-19W4	2898	1318	1190	1110	1038	881	-- *	-- *
10-17-27-19W4	2868	1318	1162	1089	1076	860	-- *	-- *
06-19-27-19W4	2792	1252	1152	1087	1010	830	--	-- *
15-13-27-20W4	2786	1218	1109	1040	976	775	659	610*
14-15-27-20W4	2771	1250	1108	1050	988	789	665	632
06-16-27-20W4	2732	1250	1080	1019	940	750	650	632
16-18-27-20W4	2736	1270	1092	1030	950	783	686	657
10-12-27-21W4	2770	1312	1139	1041	999	828	E	775
07-14-27-21W4	2601	1176	990	930	860	670	-- E	638

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-18-27-21W4	2614	1230	1040	969	917	722	E	690
11-16-27-22W4	2681	1390	1200	1140	1060	938	760E	862
10-20-27-22W4	2828	1531	1370	1309	1247	1110	909E	1034
10-29-27-22W4	2791	1526	1347	1300	1219	1097	939E	1050
07-30-27-22W4	2852	1647	1430	1388	1290	1160	980E	1090
06-15-27-23W4	2790	1632	1399	1334	1267	1150	960E	1080
07-30-27-23W4	2853	1750	1523	1450	1400	1257	1100E	1196
07-25-27-24W4	2906	1810	1616	1560	1500	1350	1170E	1270
06-26-27-24W4	2942	1868	1667	1580	1556	1400	1238E	1352
10-28-27-24W4	2913	1890	1660	1580	1557	1396	1222E	1340
10-30-27-24W4	2971	1990	1761	1703	1650	1512	1284E	1463
11-11-27-25W4	3011	2081	1856	1800	1748	1570	1342E	1518
11-24-27-25W4	2963	1972	1790	1730	1663	1533	1330E	1478
11-31-27-25W4	3010	2130	1988	1934	1898	1774	1590E	1700
11-18-27-26W4	3065	2470	2233	2186	2137	2006	1842E	1970
06-14-27-27W4	3161	2601	2390	2330	2290	2158	2020E	2128
07-15-27-27W4	3203	2640	2460	2400	2359	2235	2095E	2203
07-22-27-27W4	3200	2666	2461	2400	2350	2219	2088E	2190
11-29-27-27W4	3274	2830	2608	2541	2478	2367	2230E	2340
07-11-27-28W4	3366	2993	2790	2740	2680	2546	2418E	2520

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-14-27-28W4	3372	3033	2799	2737	2681	2560	2417E	2538
11-02-27-29W4	3646	3539	3336	3268	3200	3067	2909E	3045
10-35-27-29W4	3711	3634	3450	3360	3320	3146	2960E	3105
07-19-27-01W5	3879	4178	3928	3850	3810	3654E	3628E	ND
06-20-27-01W6	3795	4075	3810	3740	3706	3549E	3422E	ND
11-21-27-01W5	3745	3990	3720	3636	3598	3400E	3310E	ND
11-23-27-01W5	3638	3668	3430	3354	3310	3144E	2977E	ND
11-24-27-01W5	3576	3557	3343	3276	3226	3070E	2950E	ND
10-22-27-02W5	3965	4400	4166	4117	4039	3810E	3827E	3925
16-23-27-02W5	4030	4382	4187	4122	4057	3907E	3857E	ND
06-24-27-02W5	3988	4290	4100	4040	3986	3830E	3690E	ND
06-25-27-02W5	3925	4344	4050	3980	3927	3766E	3615E	ND
06-30-27-02W5	4081	4654	4418	4370	4290	4121E	4056E	ND
04-22-27-03W5	4159	5072	4772	4740	4670	4450E	4359E	ND
10-28-27-03W5	4161	4947	4792	4730	4643	4460E	4402E	4554
10-12-27-04W5	4202	5238	5062	4996	4950	4806E	4730E	4925
06-18-27-04W5	4296	5834	5620	6500	5486	5370E	5283E	ND
10-09-28-15W4	2883	1040	900	779	700	--	--	-- *
10-11-28-15W4	2830	937	830	702	648	614	--	-- *
07-13-28-16W4	2986	1126	1035	919	858	710	502	-- *

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-23-28-16W4	3071	1249	1130	1030	967	824	597	-- *
10-32-28-16W4	3213	1434	1290	1196	1126	990	910	753
10-21-28-17W4	2906	1199	1040	950	860	600	--	-- *
11-23-28-17W4	3027	1270	1154	1060	1006	824	739	614
06-29-28-17W4	2884	1246	1039	956	901	728	650	550
07-32-28-17W4	3084	1330	1250	1166	1110	948	856	760
11-17-28-18W4	2841	1026	884	807	734	559	--	-- *
11-19-28-18W4	2707	1095	970	900	830	674	--	-- *
15-21-28-18W4	2698	1099	928	846	773	--	--	-- *
07-25-28-18W4	2736	1129	928	841	786	--	--	-- *
07-20-28-19W4	2555	1030	870	789	724	--	--	-- *
11-23-28-19W4	2653	1132	1041	937	880	--	--	-- *
10-24-28-19W4	2712	1177	981	907	840	--	--	-- *
10-13-28-20W4	2748	1226	1090	1015	949	777	--	-- *
10-15-28-20W4	2729	1290	1090	1011	956	800	676	630
07-17-28-20W4	2748	1350	1150	1070	1017	848	717	787
11-18-28-20W4	2861	1458	1274	1188	1135	981	850E	910
06-13-28-21W4	2774	1368	1185	1106	1065	906	-- E	840
09-14-28-21W4	2815	1491	1232	1150	1100	957	-- E	ND
10-14-28-21W4	2810	1437	1230	1149	1099	958	-- E	880

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
06-17-28-21W4	2905	1620	1397	1298	1250	1120	1021E	1052
07-18-28-21W4	2990	1714	1505	1401	1382	1231	1140E	1152
07-21-28-21W4	2817	1482	1282	1180	1150	1010	907E	930
11-22-28-21W4	2822	1522	1318	1218	1188	1043	E	975
11-14-28-22W4	2924	1639	1474	1400	1355	1210	E	1127
10-15-28-22W4	2832	1559	1390	1282	1247	1130	E	1035
11-19-28-22W4	2975	1777	1587	1501	1469	1326	E	1250
13-20-28-22W4	2907	1705	1510	1420	1391	1260	E	1173
11-21-28-22W4	3038	1793	1628	1538	1502	1362	E	1266
10-13-28-23W4	2881	1751	1527	1439	1408	1270	E	1163
11-15-28-23W4	3052	1839	1729	1644	1598	1470	E	1410
10-17-28-23W4	3026	1850	1721	1650	1598	1478	E	1425
10-13-28-24W4	3083	2030	1822	1764	1716	1564	E	1513
06-16-28-24W4	3063	2087	1846	1795	1705	1610	E	1563
11-20-28-24W4	3045	2095	1886	1813	1767	1640	E	1586
06-13-28-25W4	2982	2090	1848	1793	1768	1604	E	1557
11-14-28-25W4	3044	2150	1932	1876	1822	1696	E	1654
11-17-28-26W4	3090	2449	2227	2190	2168	2014	E	1976
04-24-28-26W4	3030	2294	2056	2009	1957	1839	E	1781
10-18-28-27W4	3298	2886	2677	2641	2560	2450	E	2375

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-26-28-27W4	3135	2613	2378	2335	2289	2131	E	2027
06-27-28-27W4	3165	2706	2456	2400	2350	2150	E	2125
06-28-28-27W4	3177	2773	2509	2475	2396	2264	E	2217
06-25-28-28W4	3266	2950	2722	2707	2637	2526	E	2486
11-29-28-28W4	3360	3160	2990	2946	2880	2783	E	2750
06-31-28-28W4	3370	3200	3054	2994	2940	2785	E	2720
07-22-28-29W4	3729	3724	3497	3440	3393	3248	E	3214
11-23-28-29W4	3600	3570	3344	3287	3230	3080	E	3080
11-25-28-29W4	3458	3370	3190	3120	3078	2990	E	2974
06-14-28-01W5	3626	3710	3476	3429	3380	3237E	E	3257
01-15-28-01W5	3595	3700	3480	3416	3374	3160E	E	3283
11-17-28-01W5	3783	3979	3798	3708	3654	3556E	E	3574
06-19-28-01W5	3777	3960	3860	3754	3727	E	E	3653
16-15-28-02W5	3879	4283	4069	3972	3934	3750E	E	3905
10-18-28-02W5	4005	4504	4314	4267	4227	4160E	E	4204
01-20-28-02W5	3933	4340	4244	4142	4095	4023E	E	ND
10-05-28-03W5	4124	4938	4828	4797	4786	E	E	4747
11-32-28-03W5	3950	4812	4625	4509	4488	-- E	E	ND
11-30-29-15W4	3110	1366	1182	1090	1010	880	802	693
07-12-29-18W4	3039	1315	1120	1028	949	800	732	630

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-14-29-18W4	3123	1345	1220	1121	1039	901	817	726
10-18-29-16W4	3215	1490	1350	1262	1170	1030	933	776
11-29-29-18W4	3381	1628	1527	1449	1350	1220	1130	1028
04-06-29-17W4	2851	1145	1010	940	848	720	ND	522
06-11-29-17W4	3421	1886	1550	1473	1378	1260	1180	1053
06-22-29-17W4	3361	1680	1525	1441	1340	1240	ND	1033
07-13-29-18W4	3000	1279	1206	1133	1019	910	ND	728
02-18-29-18W4	2793	1170	1056	974	915	773	ND	590
07-14-29-19W4	2742	1180	1034	940	890	741	ND	-- *
08-19-29-19W4	2693	1150	1030	950	891	746	ND	-- *
10-23-29-19W4	2717	1100	977	890	838	690	ND	-- *
11-19-29-20W4	2621	1142	1046	950	924	775	ND	710
16-26-29-20W4	2687	1159	1030	956	919	768	ND	700
10-28-29-20W4	2641	1120	1025	950	918	780	ND	697
10-18-29-21W4	2663	1331	1179	1129	1056	896	E	826
10-20-29-21W4	2709	1373	1190	1110	1064	919	E	858
10-14-29-22W4	2712	1430	1267	1215	1157	1000	E	922
02-17-29-22W4	2499	1260	1130	1059	1031	890	E	820
10-18-29-22W4	2500	1340	1165	1080	1056	920	E	860
06-12-29-23W4	2779	1615	1421	1390	1368	1229	E	1170

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
06-14-29-23W4	2676	1484	1376	1320	1271	1137	E	1070
07-16-29-23W4	2587	1480	1305	1250	1178	1064	E	1010
07-17-29-23W4	2753	1690	1480	1390	1355	1260	E	1208
07-12-29-24W4	2793	1700	1548	1453	1427	1310	E	1256
08-14-29-24W4	2778	1700	1550	1469	1430	1318	E	1243
13-17-29-24W4	2873	1848	1734	1670	1605	1502	E	1446
06-12-29-26W4	2957	2005	1880	1812	1184	1658	E	1618
10-18-29-25W4	2994	2228	2016	1950	1877	1800	E	1765
10-21-29-25W4	3034	2193	1993	1902	1872	1756	E	1727
09-25-29-26W4	3034	2225	2080	2039	1969	1868	E	1821
14-30-29-26W4	3171	2600	2388	2350	2240	2160	E	2115
07-35-29-26W4	2982	2210	2066	2029	1946	1848	E	1818
06-28-29-27W4	3190	2719	2550	2530	2396	2319	E	2273
06-35-29-27W4	3200	2690	2490	2447	2408	2264	E	2230
07-33-29-28W4	3260	3040	2862	2790	2727	2660	E	2643
06-35-29-28W4	3250	2952	2760	2700	2644	2527	E	2513
06-12-29-29W4	3390	3320	3150	3080	3026	2940	E	2930
03-14-29-29W4	3431	3407	3226	3150	3110	3016	E	3010
06-23-29-29W4	3406	3370	3182	3110	3062	2979	E	2942
08-34-29-29W4	3368	3410	3207	3130	3090	2984	E	2979

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-13-29-01W5	3427	3360	3255	3180	3140	3057	E	3053
07-14-29-01W5	3481	3530	3370	3290	3240	3139	E	3130
07-15-29-01W5	3605	3693	3512	3442	3402	3300	E	3294
07-21-29-01W5	3627	3750	3572	3510	3450	E	E	3340
06-30-29-01W5	3550	3775	3610	3520	3487	E	E	3380
11-31-29-01W5	3565	3794	3640	3554	3510	E	E	3348
10-13-29-02W5	3760	4069	3870	3784	3740	E	E	3644
10-15-29-02W5	3771	4160	3970	3876	3834	E	E	3800
07-16-29-02W5	3796	4261	4049	3950	3910	E	E	3860
02-18-29-02W5	3723	4300	4082	4004	3985	E	E	ND
16-12-29-03W5	3620	4200	4010	3920	3876	E	E	ND
08-13-29-03W5	3622	4210	4023	3930	3891	E	E	ND
10-15-29-03W5	3824	4519	4370	4265	4220	E	E	ND
10-15-29-04W5	4005	5099	4940	4863	4837	E	E	ND
11-12-30-13W4	2691	858	621	590	626	--	--	*
06-23-30-14W4	2663	863	697	597	622	--	--	*
10-22-30-15W4	2790	1040	870	784	720	--	--	*
07-24-30-15W4	2668	956	737	641	582	--	--	*
10-23-30-16W4	2904	1188	1012	948	862	730	629	517
11-23-30-16W4	2932	1185	1041	960	ND	770	660	*

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-24-30-16W4	2882	1129	974	897	827	690	598	*
10-27-30-16W4	2851	1133	970	898	842	700	579	*
06-29-30-16W4	3032	1369	1190	1113	1066	915	772	696
11-12-30-17W4	3538	1927	1719	1638	1590	1437	1297	1225
07-14-30-17W4	3373	1785	1579	1503	1455	1300	1160	1095
14-29-30-17W4	3041	1427	1254	1173	1134	969	825	770
06-31-30-17W4	2949	1290	1172	1080	1031	913	758	695
04-11-30-18W4	2865	1292	1100	1006	946	810	660	610
10-12-30-18W4	2983	1405	1210	1118	1059	919	771	737
10-15-30-18W4	2901	1354	1152	1060	995	869	712	649
07-17-30-18W4	2821	1280	1085	994	942	810	659	608
10-18-30-18W4	2865	1321	1147	1068	1011	870	733	700
05-16-30-19W4	2684	1188	1004	940	889	759	601	560
11-17-30-19W4	2675	1177	1005	939	880	736	--	*
11-18-30-19W4	2631	1190	964	900	839	705	--	*
07-22-30-19W4	2797	1340	1120	1050	990	857	708	660
07-23-30-19W4	2770	1311	1080	1013	959	816	661	*
10-24-30-19W4	2762	1244	1066	994	934	791	635	*
06-16-30-20W4	2748	1307	1140	1074	1023	875	730	706
04-17-30-20W4	2721	1323	1136	1067	1019	868	725	*

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-22-30-20W4	2714	1214	1074	999	958	814	680	650
04-23-30-20W4	2707	1250	1050	986	929	803	663	*
02-24-30-20W4	2568	1120	901	850	789	659	--	*
11-18-30-21W4	2672	1428	1227	1149	1121	962	850	836
06-20-30-21W4	2692	1420	1215	1150	1120	957	860	840
09-22-30-21W4	2672	1310	1101	1040	999	866	747	708
06-24-30-21W4	2700	1326	1124	1050	1010	863	722	ND
07-19-30-22W4	2703	1540	1356	1301	1264	1128	E	1078
11-21-30-22W4	2665	1445	1290	1227	1191	1036	E	995
11-22-30-22W4	2639	1405	1235	1173	1131	985	E	944
06-23-30-22W4	2664	1425	1253	1198	1151	991	E	960
06-24-30-22W4	2665	1460	1259	1138	1162	1000	E	935
10-14-30-23W4	2615	1507	1330	1270	1229	1098	E	1040
14-19-30-23W4	2823	1734	1610	1560	1530	1400	E	1345
06-20-30-23W4	2839	1767	1605	1541	1516	1342	E	1266
11-18-30-24W4	3055	2150	1981	1931	1909	1760	E	1720
06-21-30-24W4	3012	2104	1925	1880	1838	1697	E	1660
10-22-30-24W4	2983	2050	1845	1799	1770	1620	E	1570
10-23-30-24W4	2906	1943	1734	1690	1658	1498	E	1460
06-25-30-24W4	2864	1916	1674	1636	1608	1460	E	1410

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
08-22-30-25W4	2939	2220	1970	1934	1904	1756	E	1726
06-24-30-25W4	2928	2102	1910	1870	1845	1686	E	1660
12-26-30-25W4	2966	2167	1976	1949	1917	1763	E	1726
11-08-30-26W4	3109	2567	2309	ND	2259	2093	E	2058
04-11-30-26W4	2961	2330	2069	ND	2024	1846	E	1817
10-19-30-27W4	3161	2863	2631	--	2579	2376	E	2335
02-20-30-27W4	3161	2716	2582	--	2526	2342	E	2327
10-21-30-27W4	3090	2620	2497	--	2442	2260	E	2233
10-25-30-27W4	3047	2487	2330	--	2301	2127	E	2090
10-11-30-28W4	3286	2932	2798	--	2741	2529	E	2649
13-12-30-28W4	3288	2924	2808	--	2747	2522E	E	2634
11-14-30-28W4	3289	3024	2827	--	2760	2564E	E	2640
11-15-30-28W4	3274	2980	2842	--	2770	2596E	E	2660
10-16-30-28W4	3302	3007	2915	--	2851	2652E	E	2725
06-18-30-28W4	3331	3184	3057	--	2986	2790E	E	2864
11-14-30-29W4	3299	3234	3096	--	3019	2830E	E	2883
02-14-30-01W5	3365	3414	3264	--	3171	2967E	E	3040
06-18-30-01W5	3541	3820	3616	--	3525	3309E	E	3394
10-22-30-01W5	3369	3563	3353	--	3265	3087E	E	3133
14-16-30-02W5	3657	4150	3914	--	3819	3580E	E	3700

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-26-30-02W5	3540	3905	3700	--	3610	3382E	E	3474
10-30-30-02W5	3582	4223	4000	--	3895	3691E	E	3775
10-01-30-03W5	--	4179	3990	--	3896	3685E	E	3748
06-03-30-03W5	--	4320	4146	--	4050	3810E	E	3900
16-08-30-03W5	3568	4500	4310	--	4208	4000E	E	4067
07-12-30-04W5	3762	4725	4525	--	4415	4200E	E	4332
06-05-31-15W4	2852	1040	950	830	796	652	--	*
01-14-31-15W4	2684	850	750	665	600	470	--	*
07-17-31-15W4	2752	900	836	739	690	556	--	*
10-32-31-15W4	2793	986	876	781	730	590	490	395
06-12-31-16W4	2748	895	840	756	700	575	470	375
06-06-31-17W4	2932	1247	1170	1088	1049	900	802	678
06-12-31-17W4	2998	1250	1178	1089	1048	890	767	700
06-28-31-17W4	2967	1326	1196	1100	1060	901	835	685
06-29-31-17W4	2960	1310	1190	1110	1068	915	838	690
07-04-31-18W4	2841	1282	1136	1050	1007	866	705	640
06-15-31-18W4	2901	1297	1170	1097	1049	910	750	704
04-29-31-18W4	2847	1255	1104	1029	998	856	700	660
06-21-31-19W4	2765	1280	1126	1049	1010	871	779	718
10-29-31-19W4	2784	1235	1136	1064	1032	900	780	750

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-15-31-20W4	2712	1270	1108	1013	1000	856	734	700
11-18-31-20W4	2842	1410	1281	1210	1180	1010	E	950
10-33-31-20W4	2750	1300	1192	1096	1082	914	E	864
11-14-31-21W4	2686	1382	1177	1109	1081	910	E	850
10-15-31-21W4	2650	1258	1154	1087	1053	907	E	840
06-18-31-21W4	2779	1532	1360	1287	1264	1128	E	1036
06-20-31-21W4	2743	1409	1307	1230	1203	1050	E	982
10-15-31-22W4	2748	1570	1397	1327	1303	1153	E	1090
07-17-31-22W4	2698	1565	1392	ND	1328	1160	E	1110
07-19-31-22W4	2762	1640	1470	1424	1414	1230	E	1170
07-20-31-22W4	2698	1575	1400	ND	1340	1180	E	1121
10-13-31-23W4	2837	1680	1560	1510	1506	1340	E	1272
03-16-31-23W4	2940	1969	1730	1666	1620	1520	E	1460
11-16-31-23W4	2991	1980	1809	1732	1690	1580	E	1525
11-30-31-23W4	2952	2040	1818	1732	1681	1568	E	1516
14-09-31-24W4	2936	2062	1852	1782	1755	1639	E	1595
06-10-31-24W4	2979	2050	1880	1817	1772	1657	E	1615
16-18-31-24W4	2954	2388	2180	2115	2060	1972	E	1943
14-34-31-24W4	2819	1905	1707	1650	1608	1499	E	1458
08-12-31-25W4	3046	2245	2040	1961	1922	1834	E	1750

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-16-31-25W4	3091	2387	2180	2130	2090	2006	E	1940
10-18-31-25W4	3013	2330	2126	2090	2048	1950	E	1900
16-25-31-25W4	3052	2180	2020	1976	1947	1849	E	1830
07-30-31-26W4	3178	2586	2483	2439	2410	2213E	E	2302
10-03-31-27W4	3060	2591	2450	2394	2346	E	E	2261
02-18-31-27W4	3150	2870	2662	2610	2531	E	E	2470
10-23-31-27W4	3089	2610	2452	2403	2360	E	E	2267
11-26-31-27W4	3102	2630	2466	2423	2370	E	E	2270
10-16-31-28W4	3188	3100	2885	ND	2800	E	E	2749
11-32-31-28W4	3204	3111	2956	ND	2875	E	E	2800
11-11-31-01W5	3316	3450	3244	3160	3120	E	E	2990
10-20-31-01W5	3376	3579	3400	3345	3287	E	E	3190
10-32-31-01W5	3370	3590	3412	3381	ND	E	E	3218
07-34-31-01W5	3383	3540	3302	ND	3217	E	E	3092
11-22-31-02W5	3464	3903	3676	3600	3550	E	E	3524
10-24-31-02W5	3417	3704	3480	3362	3304	E	E	3258
06-29-31-02W5	3507	4052	3814	3729	3680	E	E	3569
10-25-31-03W5	3598	4260	3966	3922	3817	E	E	3800
10-27-31-03W5	3387	4093	3920	ND	3798	E	E	3654
09-29-31-03W5	3584	4350	4170	ND	4059	E	E	3910

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-12-31-04W5	3634	4620	4390	4326	4287	E	E	4135
16-13-31-04W5	3685	4610	4405	4332	4272	E	E	4130
14-14-31-04W5	3741	4718	4506	4469	4380	E	E	4300
13-16-31-04W5	3672	4730	4570	4520	4480	E	E	4366
09-30-31-04W5	3802	4910	4729	4660	4598	E	E	4518
10-09-32-15W4	2661	830	760	690	631	480	*	*
10-32-32-15W4	2701	930	780	694	640	503	*	*
12-32-32-16W4	2718	1052	882	805	761	613	*	*
06-22-32-17W4	2757	1100	960	890	850	708	570	500
07-23-32-17W4	2748	1116	1009	894	830	689	*	*
08-34-32-17W4	2783	1090	1000	936	890	760	620	543
11-17-32-18W4	2867	1310	1166	1090	1060	923	770	720
06-30-32-18W4	2850	1330	1188	1104	1077	940	778	720
10-13-32-19W4	2827	1290	1164	1076	1050	923	765	710
11-15-32-19W4	2850	1380	1215	1127	1104	930	790	757
16-20-32-19W4	2881	1500	1282	1199	1180	1043	E	967
12-10-32-20W4	2701	1306	1149	1078	1045	880	E	810
11-15-32-20W4	2728	1330	1188	1116	1080	922	E	856
11-19-32-20W4	2764	1470	1280	1184	1130	1050	E	984
10-13-32-21W4	2754	1469	1269	1192	1162	1050	E	982

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-16-32-21W4	2736	1460	1300	1230	1200	1080	E	1002
10-18-32-21W4	2490	1310	1120	1043	1020	890	E	817
10-13-32-22W4	2772	1605	1402	1344	1304	1155	E	1102
11-20-32-22W4	2771	1720	1510	1449	1420	1278	E	1217
11-23-32-23W4	2823	1740	1592	1552	1530	1372	E	1324
07-27-32-23W4	2792	1790	1565	1494	1469	1330	E	1280
12-18-32-24W4	2862	2050	1841	1790	1750	1620	E	1580
11-27-32-24W4	2891	2010	1800	1740	1720	1580	E	1536
06-28-32-24W4	2870	2005	1816	1760	1727	1581	E	1560
05-25-32-25W4	2866	2100	1860	1812	1796	1670	E	1607
06-34-32-25W4	2937	2145	1950	--	1880	1759	E	1720
13-14-32-26W4	3036	2448	2210	2137	2090	2020	E	1981
16-19-32-26W4	3024	2500	2297	2218	2190	2088	E	2070
10-13-32-27W4	3102	2600	2400	2320	2264	2210	E	2200
07-20-32-27W4	3166	2816	2643	2578	2513	E	E	2437
07-28-32-28W4	3209	3042	2900	2838	2780	2690	E	2643
07-13-32-01W5	3259	3254	3090	3007	2940	E	E	2872
11-17-32-01W5	3403	3650	3410	--	3280	E	E	3238
03-18-32-01W5	3382	3540	3420	3349	3314	E	E	3200
10-16-32-02W5	3385	3754	3610	3516	3470	E	E	3440

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-14-32-03W5	3487	4148	3950	3903	3854	E	E	3766
06-15-32-03W5	3432	4146	3940	3880	3838	E	E	3750
05-18-32-03W5	3510	4357	4150	4076	4020	E	E	3945
15-19-32-04W5	3736	4898	4830	4673	4620	E	E	4577
05-20-32-04W5	3696	4822	4734	4610	4570	E	E	4514
03-25-32-04W5	3610	4420	4254	4194	4150	E	E	4165
07-28-33-15W4	2809	999	878	803	730	610	487	*
03-08-33-16W4	2762	1040	932	857	792	670	530	475
08-30-33-16W4	2674	986	835	756	710	560	426	380
07-28-33-17W4	2706	1045	ND	855	793	660	ND	470
07-31-33-17W4	2690	1050	916	850	796	690	549	492
07-06-33-18W4	2860	1280	1188	1118	1085	939	800	750
07-01-33-19W4	2871	1276	1200	1118	1089	960	800	722
06-07-33-19W4	2807	1338	1246	1152	ND	1003	900	834
06-10-33-20W4	2705	1265	1188	1121	1090	942	830	856
07-14-33-20W4	2745	1285	1192	1123	1106	959	850	871
06-26-33-20W4	2764	1290	1220	1153	1132	983	E	906
07-14-33-21W4	2796	1470	1370	1278	1262	1124	E	1090
11-16-33-21W4	2835	1590	1427	1354	1331	1188	E	1150
07-32-34-17W4	2788	1070	976	944	873	145	745	590

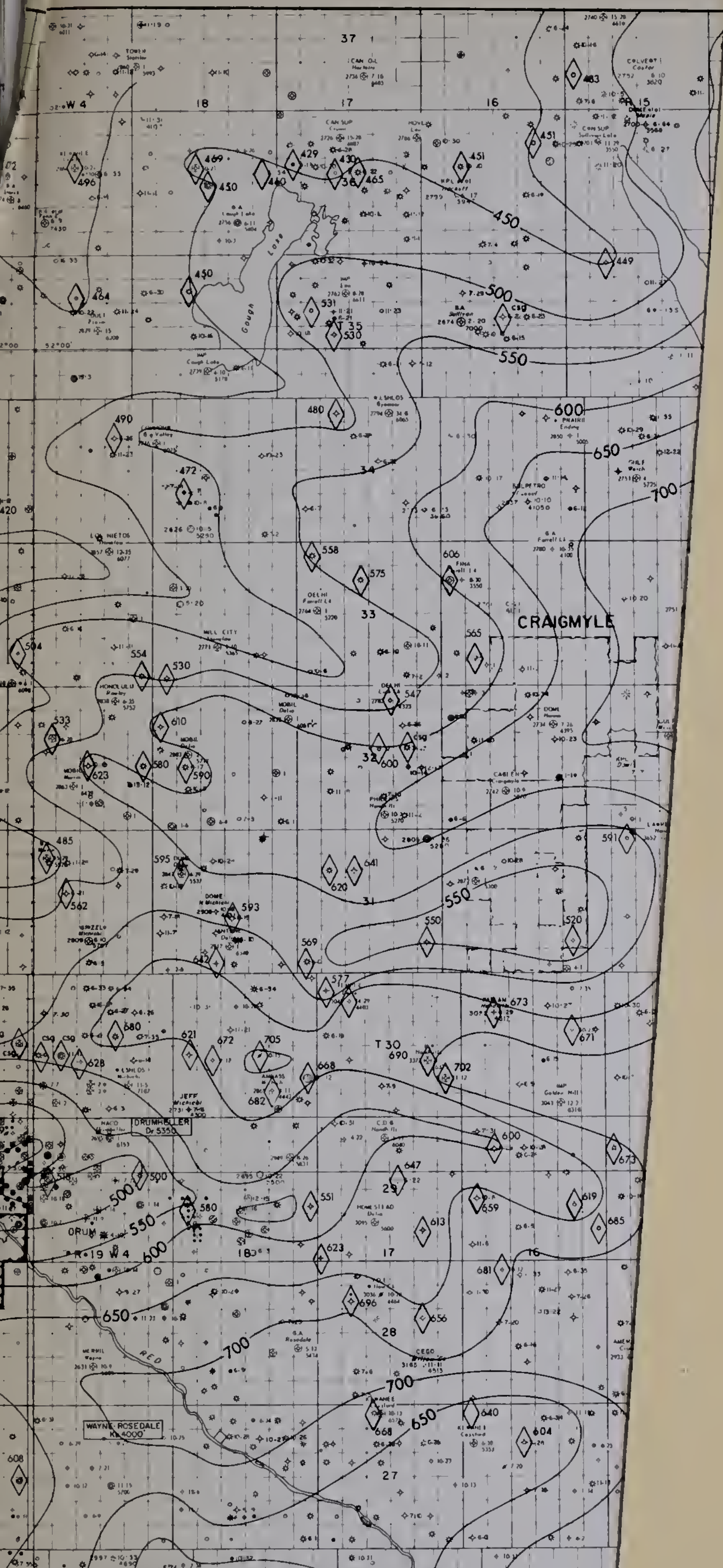
Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
03-17-34-18W4	2776	1202	1059	1018	990	820	722	*
06-26-34-19W4	2808	1290	1156	1035	1020	879	ND	800
11-12-34-20W4	2856	1440	1300	1241	1211	1070	950	1020
11-28-35-14W4	2656	750	700	610	550	380	*	*
10-32-35-15W4	2721	879	810	705	640	500	*	*
06-22-35-16W4	2854	1072	1000	905	806	690	*	*
11-16-35-17W4	2748	1042	919	850	727	657	578	512
11-20-35-17W4	2801	1110	980	927	850	735	629	579
11-28-35-18W4	2724	1075	1000	940	874	730	660	625
07-27-35-19W4	2784	1280	1140	1074	972	849	810	816
07-29-36-12W4	2698	730	599	543	468	*	*	*
06-24-36-13W4	2716	775	658	597	520	380	*	*
06-25-36-13W4	2716	757	642	586	510	493	393	*
10-20-36-14W4	2681	760	640	610	504	409	*	*
10-26-36-16W4	2811	970	849	816	705	600	505	431
10-20-36-16W4	2811	1022	892	--	756	643	554	470
06-22-36-17W4	2730	1010	846	--	729	600	--	546
06-21-36-17W4	2719	1000	870	--	740	626	517	480
10-19-36-17W4	2732	1019	898	790	770	667	550	510
06-24-36-18W4	2718	1060	910	--	780	687	*	*

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
13-15-36-18W4	2745	1160	1008	--	--	797	--	710
10-21-36-18W4	2756	1205	1026	--	1001	824	703	662
10-22-36-19W4	2897	1496	1289	--	--	1056	958	934
04-19-36-19W4	2899	1482	1292	--	--	1067	950	935
16-23-36-20W4	2766	1380	1174	--	1020	929	--	890
01-32-36-20W4	2768	1452	1239	--	--	1000	--	870
15-31-36-20W4	2828	1542	1319	1250	1190	1080	E	1050
14-35-36-21W4	2919	1703	1480	1440	1338	1276	E	1230
06-33-36-21W4	3037	1883	1656	1906	1530	1454	E	1397
10-16-36-21W4	2918	1760	1524	--	1410	1332	E	1290
06-08-36-21W4	2770	1646	1390	--	1280	1200	E	1145
10-14-36-22W4	2905	1810	1547	1522	1443	1366	E	1334
06-17-36-22W4	2970	1960	1720	1692	1619	1480	E	1500
10-15-36-23W4	2955	1954	1742	--	1650	1570	E	1554
07-20-36-23W4	3092	2105	1930	1905	1833	1750	E	1737
10-25-36-24W4	3051	2120	1940	1912	1830	1750	E	1730
06-32-36-24W4	3100	2260	2080	--	2000	1890	E	1875
06-26-36-25W4	3054	2274	2090	--	2046	1914	E	1890
06-17-36-25W4	3265	2547	2362	--	2250	2160	E	2167
07-13-36-27W4	3179	2630	2486	--	2350	E	E	2280

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-20-36-27W4	3039	2665	2458	--	2336	E	E	2293
07-24-36-28W4	2998	2730	2516	--	2388	E	E	2339
06-28-36-28W4	3013	2805	2600	--	2443	E	E	2410
10-23-36-01W5	3082	2930	2780	--	2610	E	E	--
10-29-36-01W5	3021	3050	2885	--	2725	E	E	2734
10-22-36-02W5	2999	3112	2950	--	2800	E	E	2787
11-29-36-02W5	3041	3266	3050	--	2910	E	E	2853
16-12-36-03W5	3125	3475	3270	--	3139	E	E	3123
04-17-36-03W5	3196	3742	3570	--	3416	E	E	3389
10-18-36-03W5	3205	3770	3604	--	3436	E	E	3408
08-24-36-04W5	3230	3800	3627	3509	--	E	E	3435
10-09-36-04W5	3292	4078	3912	3790	3755	E	E	3704
07-13-36-05W5	3303	4211	4032	3914	3846	E	E	3822
04-09-36-05W5	3387	4606	4423	4327	4218	E	E	4190
02-18-36-05W5	3443	4730	4541	4445	4345	E	E	4320
07-09-36-08W5	3920	6148	6018	5916	5816E	E	E	5860
10-21-37-13W4	2784	930	770	712	577	500	*	*
07-29-37-13W4	2759	873	734	679	645	484	*	*
06-07-37-15W4	2704	868	698	665	562	457	*	*
06-10-26-01W5	3720	3847	3560	3490	3449	3290E	E	3331

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
14-16-26-01W5	3707	3880	3580	3510	3473	E	E	3356
10-22-26-01W5	3667	3750	3485	3445	3398	E	E	3245
10-27-26-01W5	3645	3763	3498	3448	3400	E	E	3300
07-33-26-01W5	2798	3900	3689	3627	3582	E	E	3450
07-26-26-02W5	3919	4231	4025	3979	3930	E	E	3774
16-10-27-02W5	4030	4420	4211	4130	4093	E	E	3994
07-15-27-02W5	3999	4438	4190	4110	4060	E	E	3945
10-22-27-02W5	3965	4400	4164	4117	4039	E	E	3925
08-26-27-02W5	4015	4417	4180	4100	4050	E	E	4010
11-34-27-02W5	3996	4420	4200	4125	4077	E	E	4037
10-03-28-02W5	3980	4395	4180	4091	4052	E	E	4026
10-09-28-02W5	3987	4436	4230	4130	4092	E	E	4064
16-15-28-02W5	3879	4284	4069	3972	3933	E	E	5905
06-22-28-02W5	3886	4294	4094	4000	3960	E	E	3868
06-28-28-02W5	3955	4454	4210	4119	4063	E	E	4038
12-33-28-02W5	3899	4490	4189	4090	4050	E	E	4010
06-10-29-02W5	3845	4309	4070	3970	3934	E	E	3899
10-15-29-02W5	3771	4160	3970	3877	3833	E	E	3800
06-23-29-02W5	3797	4111	3956	3864	3828	E	E	3791
10-27-29-02W5	3714	4085	3911	3819	3780	E	E	3750

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-33-29-02W5	3647	4080	3885	3804	3767	E	E	3730
10-09-31-02W5	3531	4003	3814	3720	3671	E	E	3651
10-24-31-02W5	3417	3704	3480	3390	3370	E	E	3327
11-22-31-02W5	3464	3903	3676	3600	3550	E	E	3524
06-29-31-02W5	3507	4050	3814	3729	3680	E	E	3640
11-31-31-02W5	3538	4120	3890	3790	3750	E	E	3700
10-10-32-02W5	3391	3780	3560	3470	3430	E	E	3389
10-16-32-02W5	3385	3754	3610	3514	3470	E	E	3440
04-21-32-02W5	3397	3795	3650	3557	3511	E	E	3500
04-29-32-02W5	3470	3963	3775	3680	3648	E	E	3605
04-31-32-02W5	3515	4030	3825	3740	3696	E	E	3662
10-04-33-02W5	3322	3709	3534	3450	3406	E	E	3360
07-11-33-02W5	3316	3622	3450	3363	3327	E	E	3282
11-16-33-02W5	3326	3684	3522	3440	3408	E	E	3349
11-28-33-02W5	3343	3712	3530	3440	3376	E	E	3352
06-32-33-02W5	3243	3650	3474	3376	3333	E	E	3294
10-09-34-02W5	3233	3540	3396	3306	3260	E	E	3225
11-23-34-02W5	3242	3514	3325	3238	3192	E	E	3133
16-32-34-02W5	3119	3516	3280	3190	--	E	E	3112
10-26-35-02W5	3111	3349	3104	3026	--	E	E	2950



CRAIGMYLE
T 30
T 25
R 19 W 4

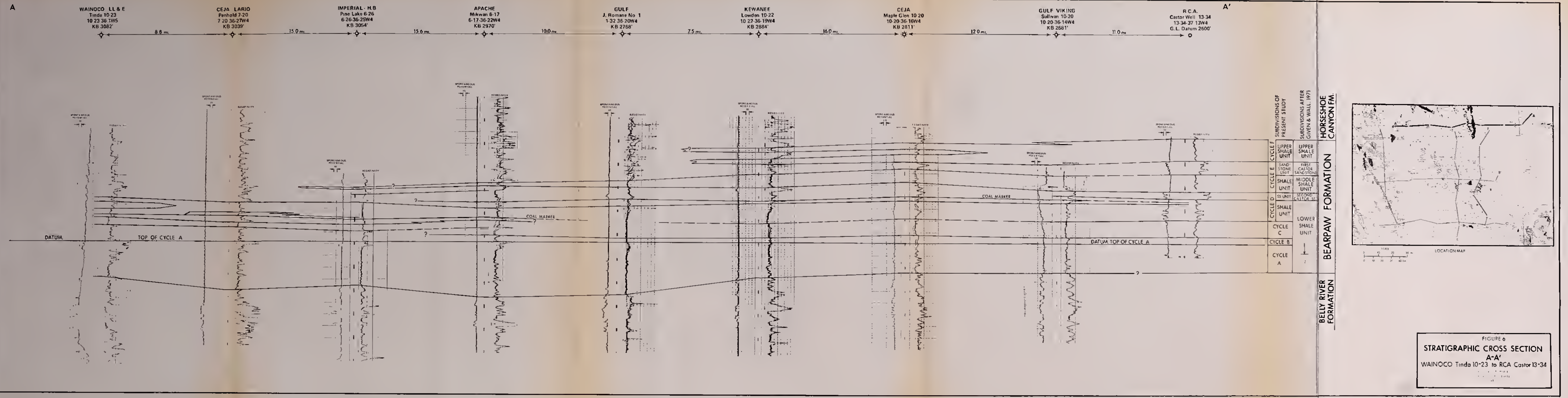


FIGURE 6
STRATIGRAPHIC CROSS SECTION
A-A'
WAINOCO Tinda 10-23 to RCA Castor 13-34

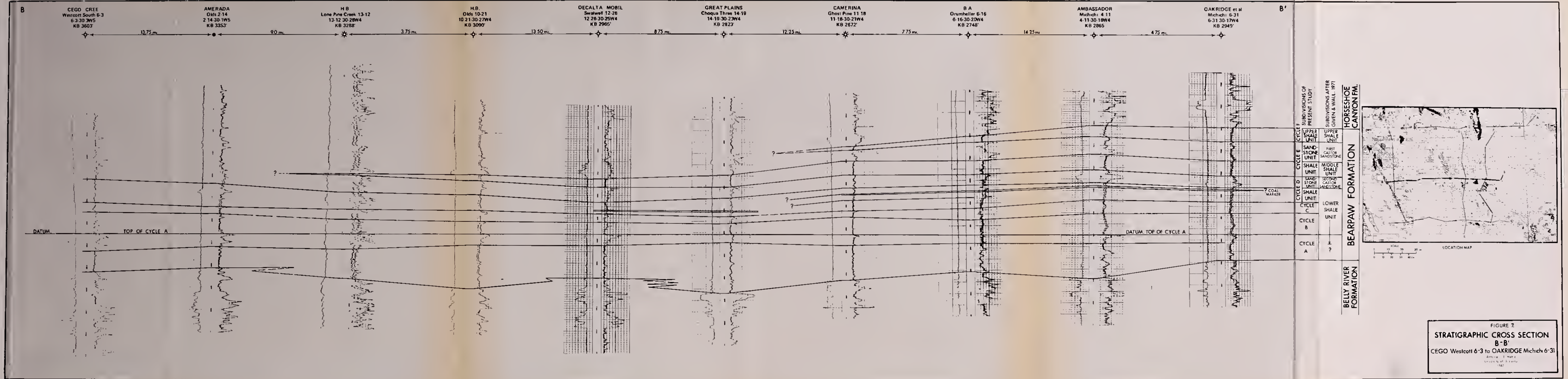


FIGURE 7

STRATIGRAPHIC CROSS SECTION B-B'

CEGO Westcott 6-3 to OAKRIDGE Michichi 6-31

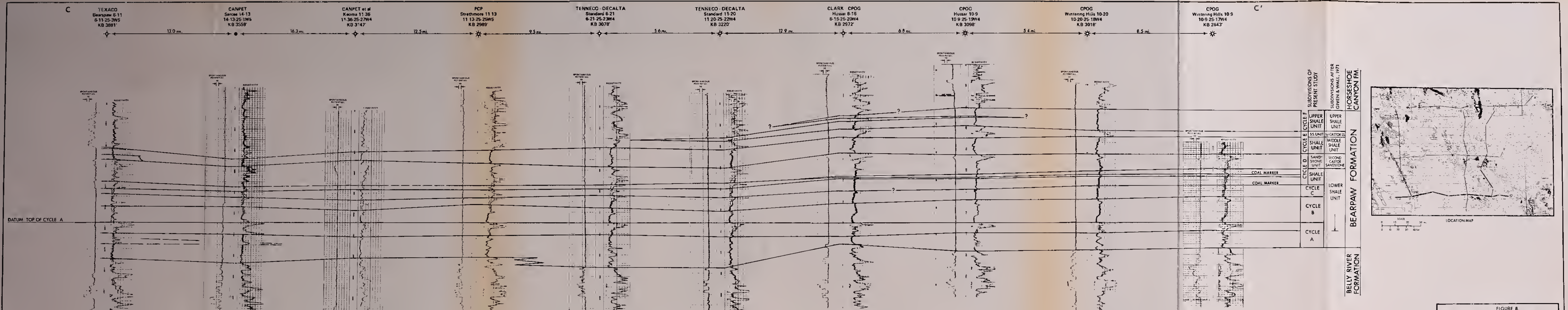


FIGURE 8.

STRATIGRAPHIC CROSS SECTION C-C'

TEXACO Bearspaw 6-11 to CPOG Winter H. 10-9

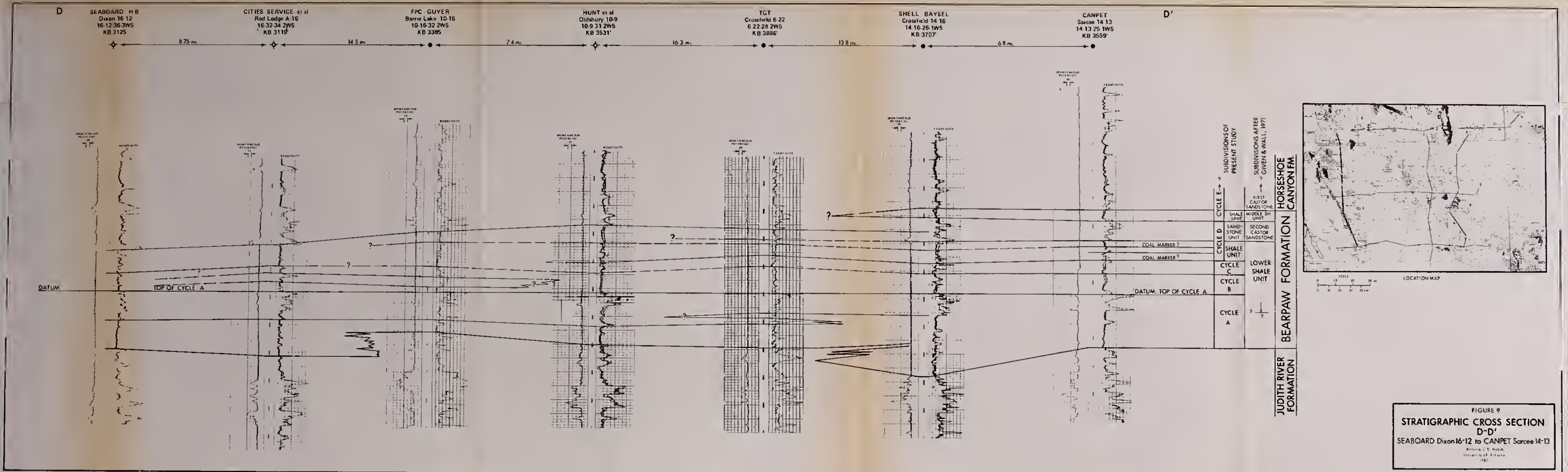


FIGURE 9

STRATIGRAPHIC CROSS SECTION D-D'

SEABOARD Dixon 16-12 to CANPET Sarcee 14-13

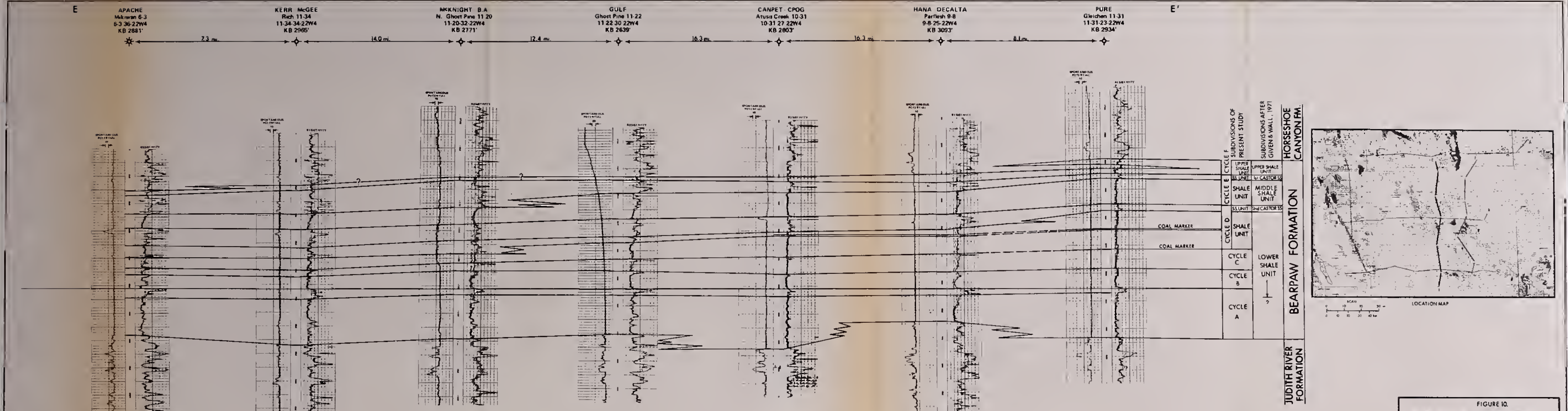


FIGURE 10.

STRATIGRAPHIC CROSS SECTION E - E'

APACHE Mikwan 6-3 to PURE Gleichen 11-31

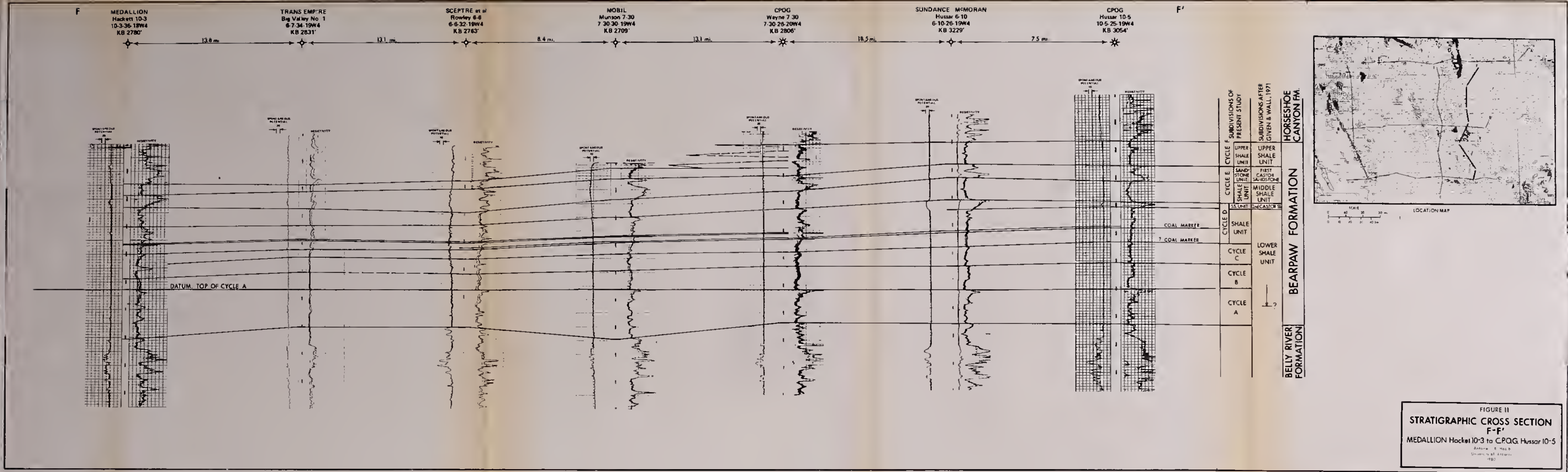


FIGURE II
STRATIGRAPHIC CROSS SECTION F-F'
MEDALLION Hocket 10-3 to C.P.O.G. Hussar 10-5

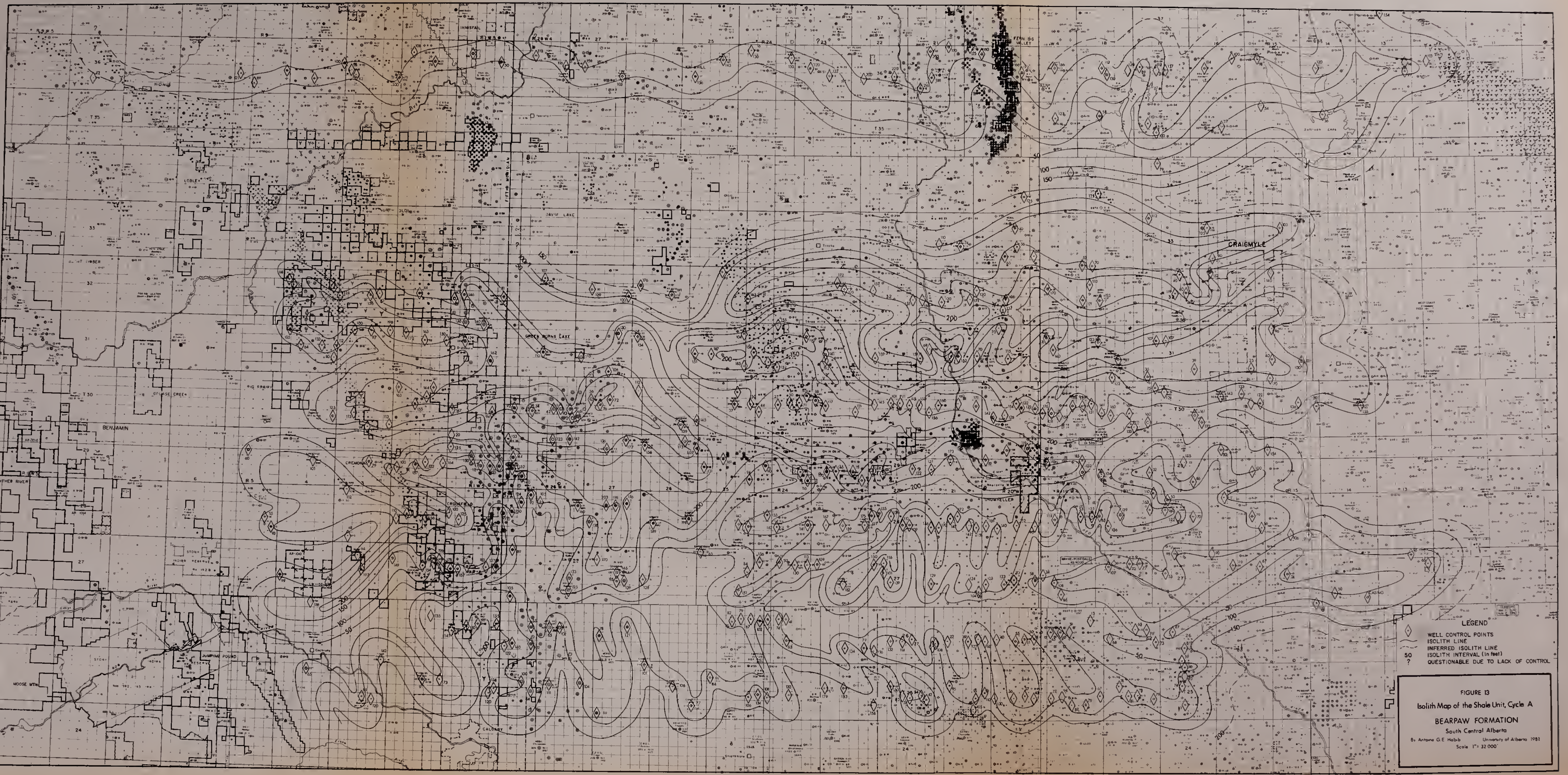


FIGURE 13
Isolith Map of the Shale Unit, Cycle A
BEARPAW FORMATION
South Central Alberta
By Antoine G.E. Habib University of Alberta 1981
Scale 1" = 32 000'

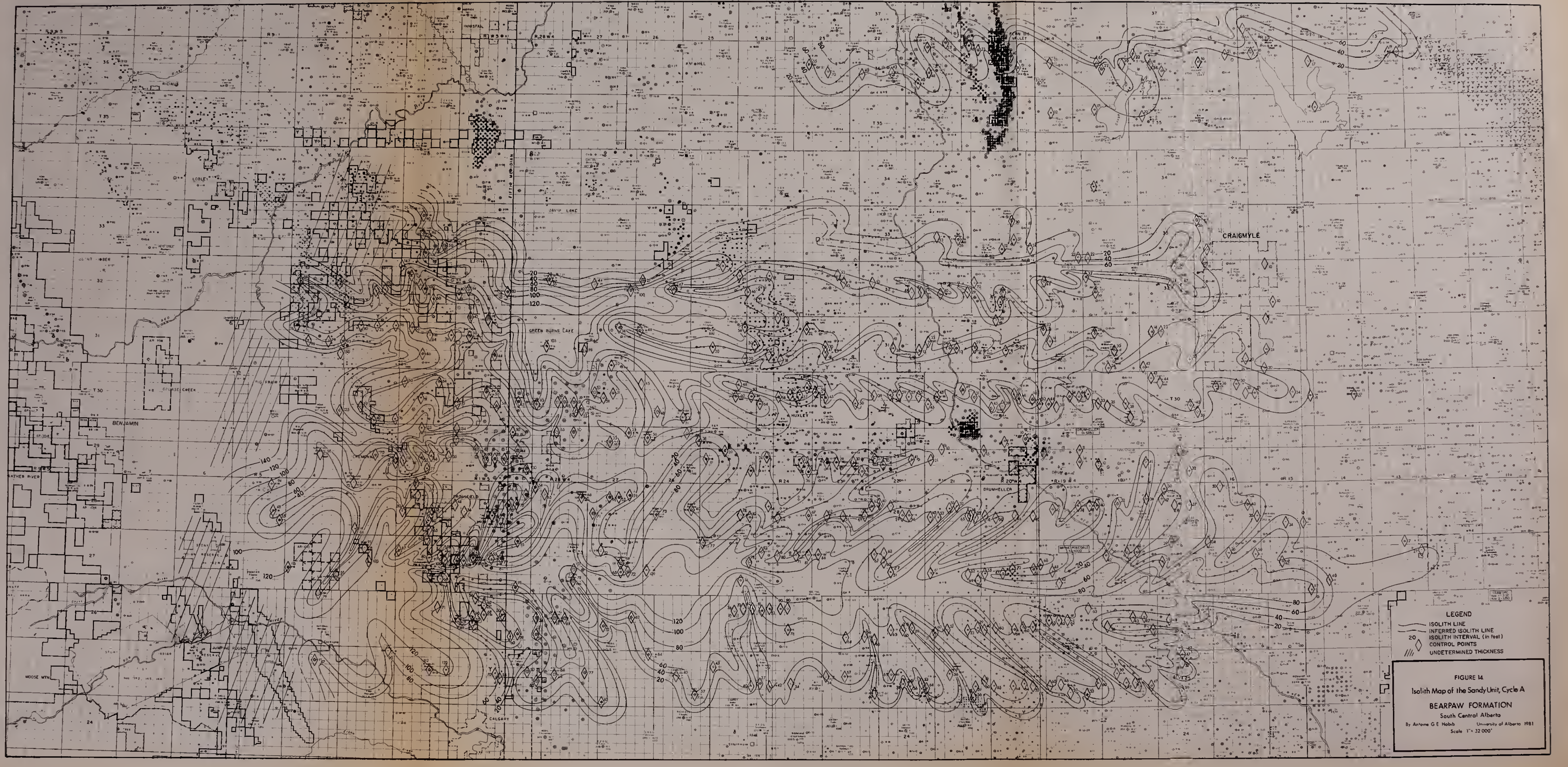


FIGURE 14

Isolith Map of the Sandy Unit, Cycle A

BEARPAW FORMATION

South Central Alberta

By Antoine G E Habib University of Alberta 1981

Scale 1" = 32 000'

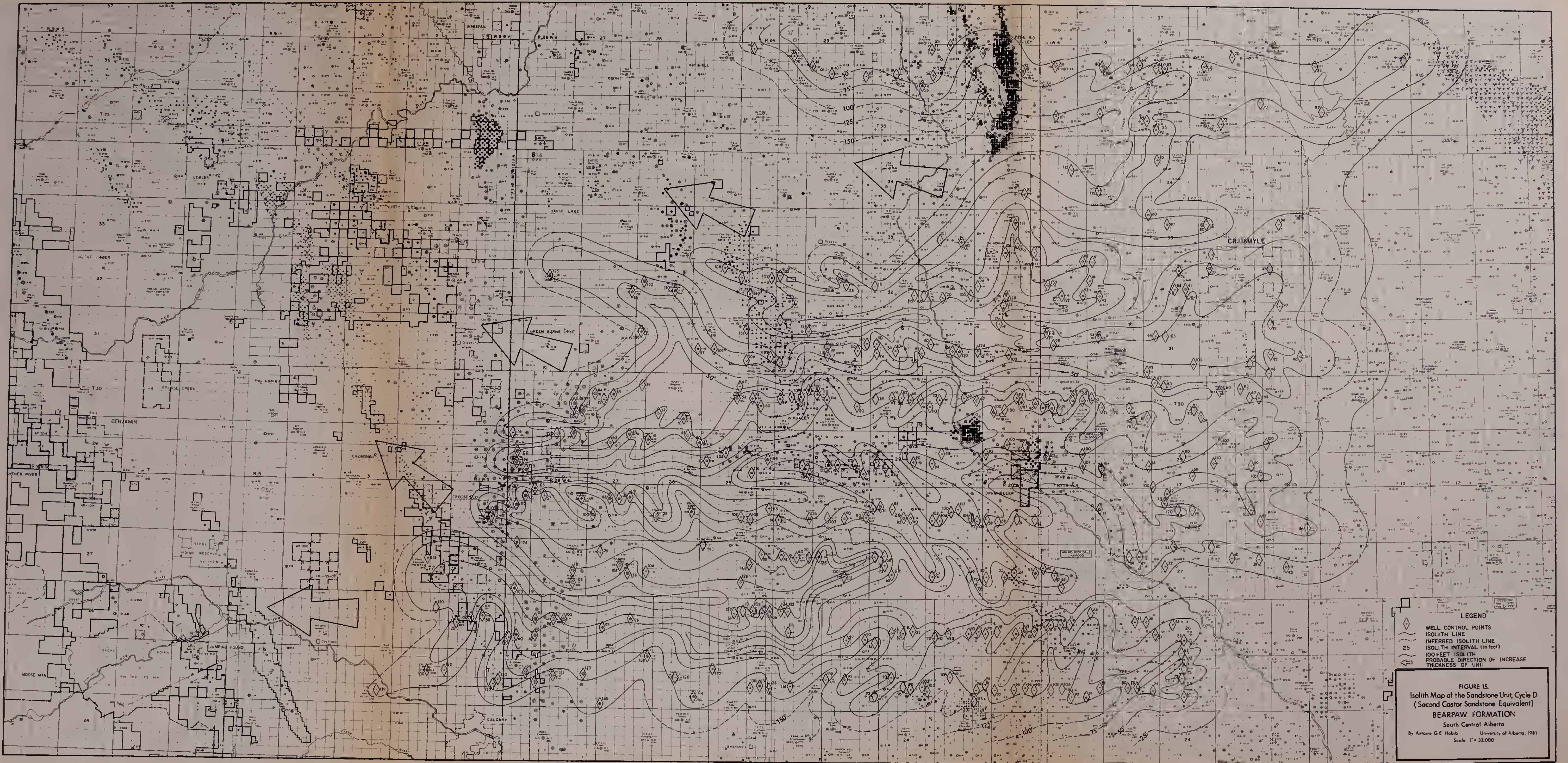


FIGURE 15.
Isolith Map of the Sandstone Unit, Cycle D
(Second Castor Sandstone Equivalent)
BEARPAW FORMATION
South Central Alberta
By Antoine G.E. Habib University of Alberta, 1981
Scale 1" = 32,000'

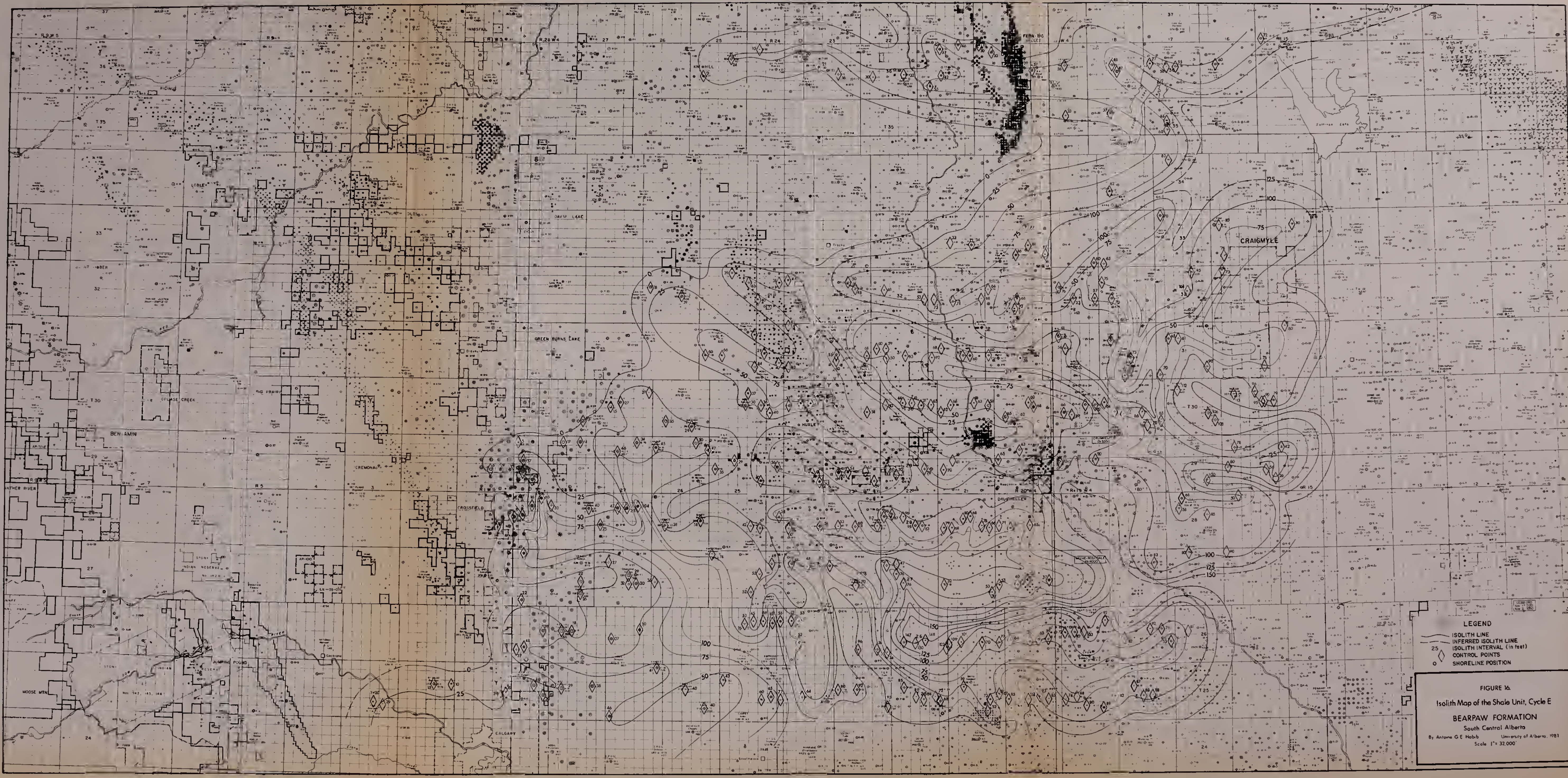


FIGURE 16.

Isolith Map of the Shale Unit, Cycle E

BEARPAW FORMATION

South Central Alberta

By Antoine G E Habib University of Alberta, 1981

Scale 1" = 32,000'

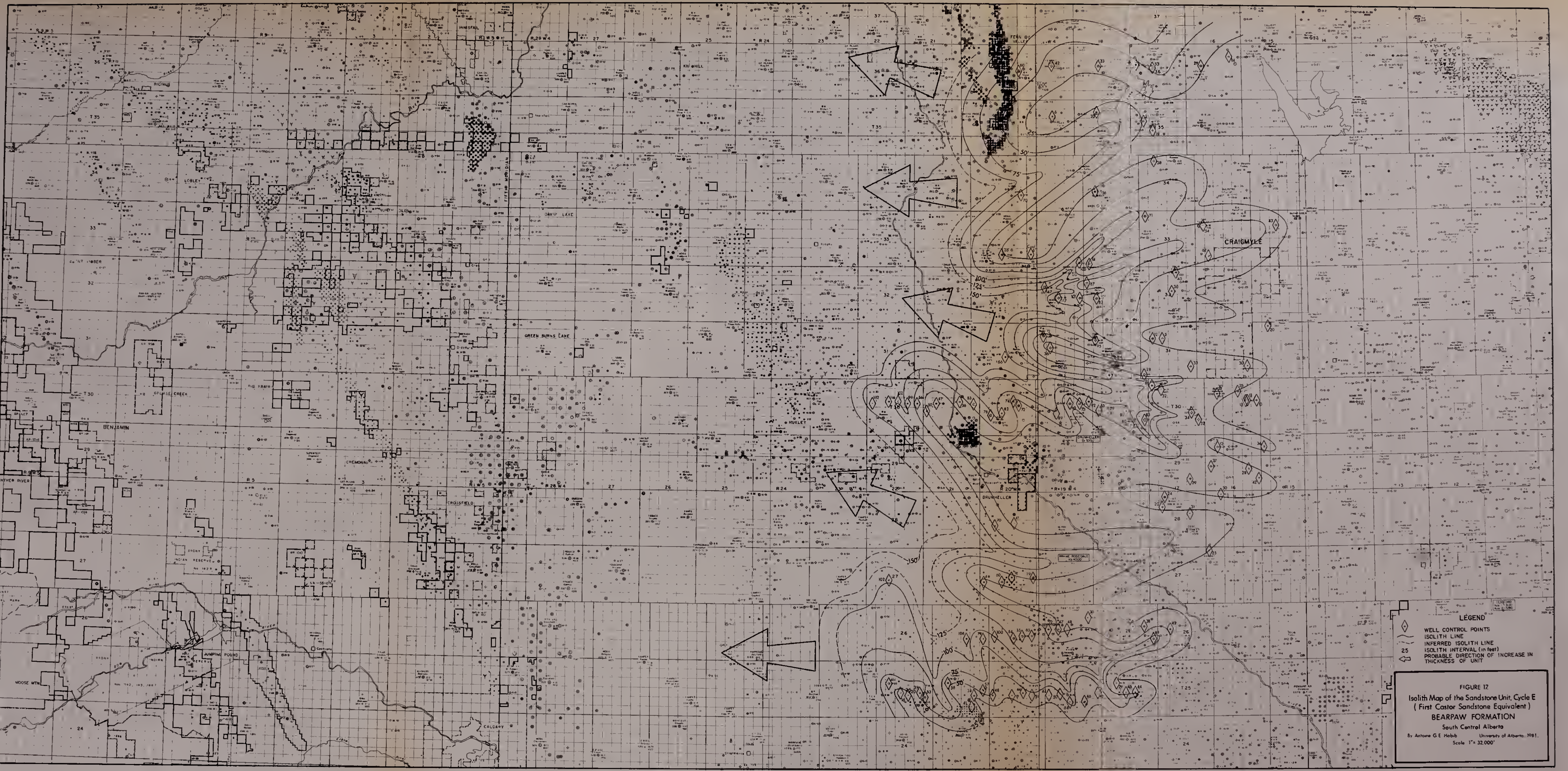


FIGURE 17
Isolith Map of the Sandstone Unit, Cycle E
(First Castor Sandstone Equivalent)
BEARPAW FORMATION
South Central Alberta
By Antone G.E. Habib University of Alberta 1981.
Scale 1" = 32,000'

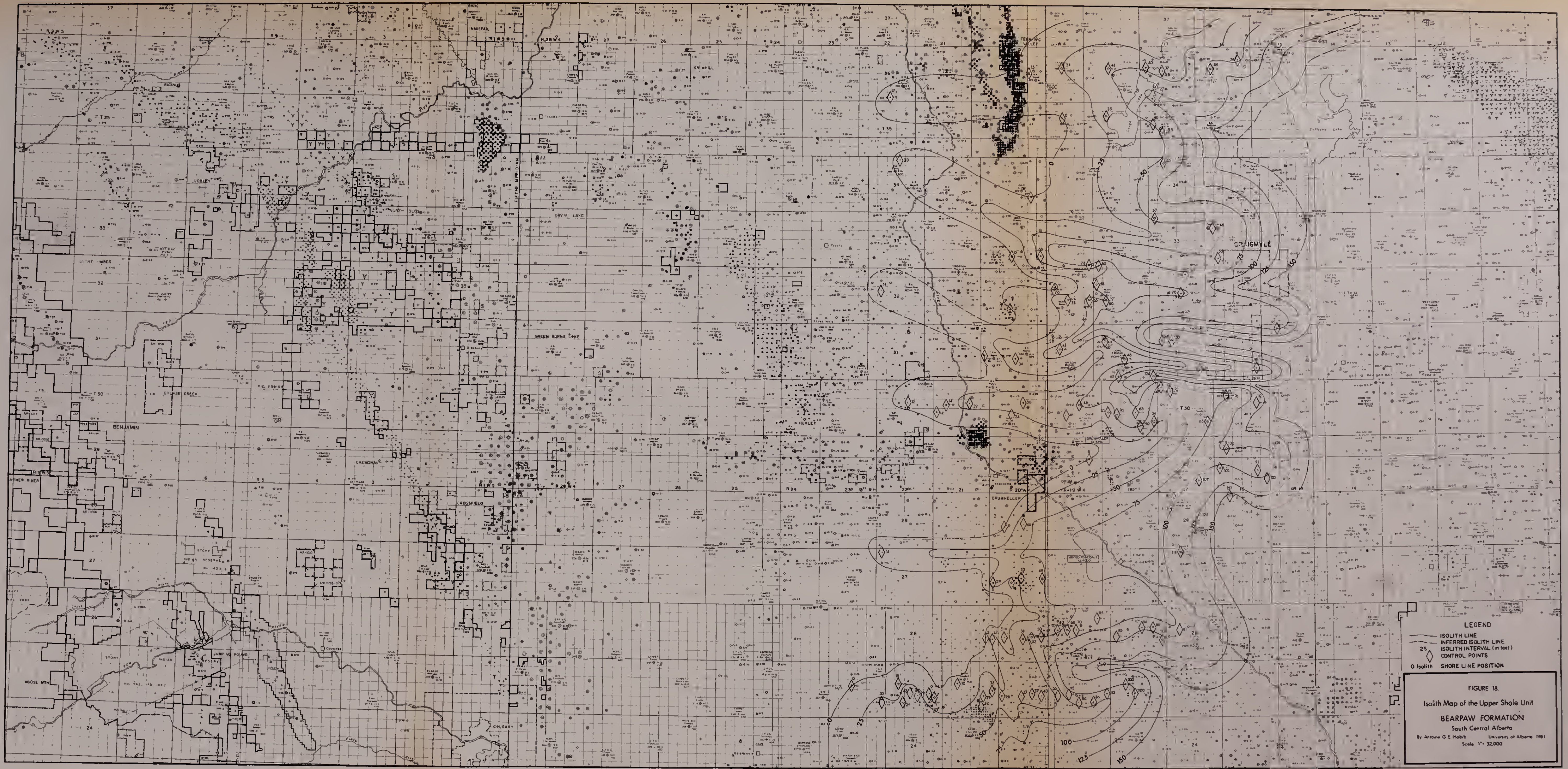


FIGURE 18.

Isolith Map of the Upper Shale Unit

BEARPAW FORMATION

South Central Alberta

By Antoine G.E. Habib University of Alberta 1981

Scale 1" = 32,000'

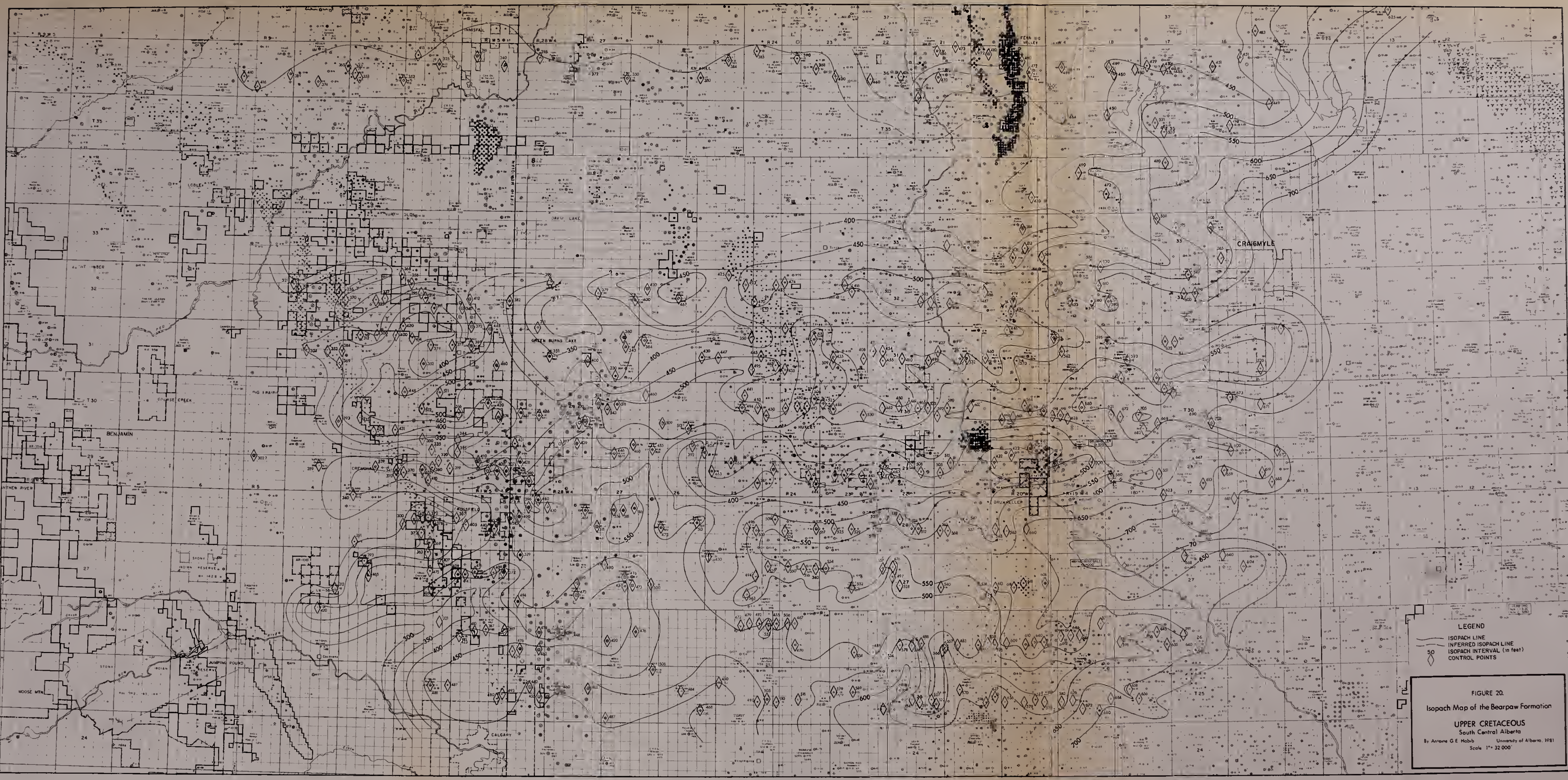


FIGURE 20.

Isopach Map of the Bearpaw Formation

UPPER CRETACEOUS
South Central Alberta

By Antoine G.E. Habib University of Alberta, 1981

Scale 1" = 32 000'